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JOS. M. WILSON, President, in the chair.

THE RÖNTGEN RAYS.

BY EDWIN J. HOUSTON, PH.D., AND A. E. KENNELLY, SC.D.

The announcement of a scientific discovery has seldom produced so intense an excitement throughout the civilised world as has that made in December last, by Professor W. C. Röntgen, of Wurzburg, Bavaria, concerning his ability to obtain a photograph of the bones of an animal through its living integument. His announcement, indeed, has created so intense an excitement and enthusiasm, that, although the discovery is practically only a few weeks old, yet his experiments have been repeated in all parts of the world.

The authors have been requested, by the Franklin Institute, to present to its members a *résumé* of the facts that

are known concerning Röntgen's discovery, as well as of some of the theoretical explanations which have been offered in connection therewith.

The paper in which Professor Röntgen announced his discovery was addressed to the Wurzburg Physico-Medical Society in December last.

Professor Röntgen describes in this paper the method he adopted for obtaining the peculiar form of radiant energy, now generally known as the Röntgen rays, and for which he proposed the provisional name of X rays. On passing the discharge from a large Ruhmkorff coil through a suitably exhausted tube of the Hittorf, Lenard, or Crookes type, a peculiar effect, invisible to the eye, is produced in the region outside the tube. This effect, however, can be rendered visible by the fluorescence excited in a paper screen, painted with a solution of barium-platino-cyanide. In vacuum tubes of the type referred to, the passage of the proper discharge is attended by the production of rays, called cathode rays; that is, rays projected in straight lines from the cathode, or negative electrode, of the vacuum tube.

It was observed by Crookes that these cathode rays were not produced to an appreciable degree until a certain high vacuum was reached. Crookes showed, by his experiments that, in so high a vacuum, matter could be regarded as existing in a fourth state or condition, to which he gave the name of the *radiant* or *ultra-gaseous state*. The highly rarefied matter contained in these vacua is capable of producing characteristic effects when subjected to heat or electrification. For example, when an electric discharge is passed through the residual atmosphere in the tubes, the molecules are shot off in rectilinear paths from the cathode, and wherever they strike the walls of the glass tube, or suitable bodies placed in the tube, they produce a faint fluorescent light. Crookes showed that these cathode rays were capable of being deflected from their original rectilinear paths by the action of a magnet. They thus behave in conformity with the view that they consist of streams of negatively charged molecules, the deflecting action being merely a particular kind of electro-magnetic action, well

seen in the deflection of a voltaic arc by a magnet, or in the electro-magnetic motion of the armature of the electric motor.

Hertz discovered that the cathode rays readily pass through thin films or screens of mica, or even of metal. He showed that, in fact, metallic films were even more transparent to the cathode rays than films of mica. For example, when such metallic screens were interposed in the vacuum tube between the cathode and the glass walls on the tube opposite the cathode, fluorescence was still developed in portions of the tube which would have corresponded to the shadow of the screen, had it been opaque.

Lenard, at one time an assistant of Hertz, took the matter up, and showed that fluorescence could be produced by the cathode rays outside the glass vacuum tube. For this purpose, he placed a small window of aluminum in the walls of his vacuum tube, so that the stream of cathode rays would impinge upon this window. A change of some sort appeared to occur at the window. While in the tube, the rays proceeded along straight lines, unless deflected by a magnet; outside the window they preserved rectilinear paths, but radiated in all directions from the window as a source.

These rays, produced outside the vacuum tube by the cathode rays within the vacuum tube, may be called the Lenard rays.

In common with the cathode rays, the Lenard rays possess the power of producing fluorescence in fluorescent substances upon which they impinge. They differ from the cathode rays in the fact that, in the air, they are visible to the eye as a faintly glowing stream or pencil, which rapidly diminishes in intensity, at comparatively short distances from the window. All the effects of the Lenard rays became lost at a distance of a few centimeters from the window, so rapid is their absorption in the air or other media. Hydrogen was found to be the least absorptive, that is, the most transparent medium; but hydrogen, under great pressure, becomes more opaque. Lenard showed that many of the metals are partially transparent to his rays, and that sensi-

tive photographic plates, or films, are quickly blackened by their influence. In fact, Lenard took shadow photographs of opaque or semi-opaque bodies, by interposing them in the path of the rays before they impinged upon the sensitive photographic plate held in a light-tight box, provided with an aluminum cover or slide. Lenard found that the opacity of different substances to his rays varied, approximately, with their density.

In the paper before referred to, Röntgen announced that, when a suitably exhausted vacuum tube is placed under a cover of blackened pasteboard, fluorescent effects can be obtained, not merely at a distance of a few centimeters, but even at a distance of 2 meters, in air. He employed for this purpose a paper screen painted with a solution of barium-platino-cyanide. The Röntgen rays, unlike the Lenard rays, are invisible to the eye, even close to the vacuum tube. No window is necessary in the vacuum tube to produce the Röntgen effect, although Röntgen has produced the effect through an aluminum window. As in the case of the Lenard rays, the Röntgen rays are radiated in rectilinear paths in all directions from the portions of the walls of the tube subjected to the bombardment of the cathode rays.

It will thus be seen that a similarity exists between the Lenard and the Röntgen rays, so far as their method of production is concerned. In each, the source of the rays is to be traced to the impact of the cathode rays upon the walls of the vacuum tube in which they are produced. In each, the rays possess the power of exciting fluorescence in suitable bodies on which they impinge; in each, they possess the power of passing through substances opaque to ordinary light, the opacity in each case increasing apparently with the density, although not in direct proportion.

The Röntgen rays appear to differ from the Lenard rays in the fact that they are not so readily absorbed by air or other media. If no absorption existed, the intensity of the rays would, of course, diminish as the square of the distance from their source. Röntgen claims that he has observed that this rate of diminution in the intensity of his rays does exist within the limits of observational error. This peculi-

arity of the Röntgen rays has greatly enhanced their practical value.

It will be seen, therefore, that the difference between the Lenard and the Röntgen rays is not marked. The difference appears to be one of degree rather than of kind. There is, however, at least one difference in the rays under discussion. Lenard found that his rays are not appreciably deflected by a magnet when passing through air, but that deflection does occur when his rays were allowed to traverse a highly exhausted chamber. Röntgen mentions that, up to the present time, he has not been able to produce any deflection of his rays by a magnetic field. This has been confirmed by Dr. Oliver Lodge. Röntgen is also experimenting with the action of an electrostatic field, but we believe he has not, as yet, announced any result.

The curious fact pointed out by Röntgen, in the paper before referred to, of the ability of his rays to produce, upon a sensitive photographic plate, photographs of the shadows of, say, the bones of the hand, in the living subject, has naturally caused great popular excitement and interest. There can be no doubt that this fact will prove of great value to the surgeon, especially if, as would seem probable, means are perfected for the production of these rays with increased power.

Röntgen states, as a result of observation, that his rays are apparently incapable of reflection, refraction or interference. If refraction does exist, it must be of very limited amount. These facts have led Röntgen to suggest that his rays are not light in the ordinary physical sense of the term; that is, that they do not consist of a transverse vibration propagated in the ether, according to electro-magnetic laws, but that possibly they may be a longitudinal motion propagated in the ether, a condition which Prof. S. P. Thompson has happily named "ultra-violet sound," and which others have called "ethereal sound" and "longitudinal light."

The details of the method for producing Röntgen rays do not appear yet to have been published by Prof. Röntgen. Physicists, however, have very generally reproduced them, although thus far the shadowgraphs obtained in this coun-

try do not present the sharpness and depth which apparently characterise Prof. Röntgen's shadowgraphs.

The authors have successfully obtained Röntgen rays by the use of a large induction coil excited directly by storage cells through an interrupter, the secondary terminals of the induction coil being led directly to the terminals of the Crookes tube. In this case the cathode is the source of cathode rays in the tube, and the surface of the glass, opposite to the cathode, where fluoresence is produced, is the source of the Röntgen rays. We have found, however, as others have done, that by far the best results are obtained by using a high-frequency discharge through the Crookes tube. This is conveniently done by exciting the primary of the induction coil from a 50-volt alternating-current circuit, such as is employed for supplying incandescent lamps on commercial alternating-current circuits, at, say, 15,000 alternations per minute. The secondary terminals of the induction coil are led to a battery of Leyden jars through the primary coil of a Tesla induction coil immersed in oil. The secondary terminals of the Tesla coil are then connected directly to the Crookes tube. Under these conditions torrents of high-frequency discharges pass between the discharging knobs of the induction coil, which are separated to a distance of, perhaps, 5 millimeters, the frequency being determined by the capacity and inductance of the Leyden jar circuit, including the Tesla primary. These high-frequency discharges induce, in their turn, high-frequency and high-tension discharges in the Crookes tube. In such cases both electrodes of the Crookes tube are alternately cathodes, and the glass wall opposite to each electrode becomes fluorescent, and, therefore, the source of Röntgen rays.

The practical difficulties in connection with the production of the Röntgen rays arise from the fact that the Crookes tubes, as ordinarily constructed, are not designed to stand the molecular bombardment of the cathode rays, when of fairly great power, for any considerable length of time. Since the ordinary Röntgen shadowgraphs require exposures lasting, usually, half an hour, and sometimes several hours, a great liability exists to excessive heating of the

tubes and the destruction of their vacua. Indeed, at times, the heat produced by the molecular bombardment of the cathode rays is sufficient to melt the glass walls of the tubes, as the authors, most probably in common with others, have ascertained to their loss.

Since the high-frequency discharges obtained by the use of a Tesla coil are not characterised by such marked heating effects, either at the walls of the tubes or in the electrodes, they are greatly to be preferred for producing shadowgraphs. Independently of this, however, they appear to produce a more powerful image. Possibly the velocity with which the molecules are projected from the cathode, or their number, or both, are increased.

A simple form of Tesla coil may be made by winding a primary of about eighty turns of No. 19 A. W. G. cotton-covered copper wire over a glass tube about ¾ inch in diameter, and inserting this inside a slightly larger glass tube, over the surface of which has been wound a secondary of about 400 turns of about No. 31 A. W. G. fine silk-covered copper wire. The coil is then immersed in some high insulating oil, such as rosin oil.

In the shadowgraph of such portions of the human body as, for example, the hand, the bones cast the most marked shadows, and the surrounding tissues produce shadows intermediate in intensity. The density of the shadow which is cast upon the plate depends apparently upon the total quantity of matter which the rays have to traverse. Thus, a short passage through a dense substance produces the same depth of shadow as a long passage through a rare medium. In order to obtain sharp definition, the use of a diaphragm is recommended. An iron or lead plate provided with a suitable aperture, and placed between the tube and the photographic plate, is suitable for the purpose.

A photographic copy of a shadow photograph obtained by Röntgen, of a human hand, is here presented on the screen. It will be observed that the shadows cast by the bones are much darker than those cast by the cartilages, sinews, muscles, veins, arteries or integuments.

It is stated by Prof. Silvanus P. Thompson that distinct

shadow photographic effects have been produced by the ordinary arc light, so that it would appear that some Röntgen effect is produced by the voltaic arc.

It has recently been discovered by Prof. Pupin and others that, in order to obtain the cathode rays in a vacuum tube, it is not necessary to employ electrodes within the tube itself; but if pieces of tinfoil are placed outside the vacuum tube, and the terminals of the high tension coil are connected therewith, discharges are produced in the vacuum tube by electrostatic induction. These discharges produce fluorescence in the tube, and the fluorescent glass is again the region of Röntgen rays.

This would appear to show that the Röntgen rays are produced by molecular bombardment by the molecules of the residual atmosphere of the high vacuum, and that the metallic cathode is only to be regarded as an auxiliary means for producing this bombardment.

Prof. J. J. Thomson has recently made the extremely important discovery that the Röntgen rays tend to discharge an electrified body on which they impinge, and this whether the charge of the body be positive or negative. Prof. Thomson finds that a charged body constitutes a more sensitive test for the presence of the Röntgen rays than is afforded by either a sensitive photographic plate or a fluorescent screen. This effect takes place whether the charged body be covered by a layer of paraffine, sulphur or vulcanite. In other words, as Professor Thomson points out, *the remarkable fact exists that an insulating layer becomes electrically leaky while being traversed by the Röntgen rays.*

Hitherto no means have been known, beyond mere thermal influence, for altering the electrical insulating power of solid materials by radiant energy of any character. The discovery of this property of effecting electric discharge makes the ray far more wonderful and important to physicists than its property of penetrating opaque solids as displayed in shadowgraphs.

The degree of exhaustion in the vacuum tube, which is the source of the Röntgen rays, appears to be that required for rectilinear molecular bombardment. Edison has shown,

experimentally, that below a certain exhaustion the Röntgen effect is negligibly small, while above a certain exhaustion the intensity of the effect again decreases. In general, it may be said that a vacuum which produces a bluish violet light on the passage of the discharge is too low to produce the Röntgen effect. The best results are obtained when little or no discharge is visible within the tube, but the walls are rendered fluorescent with a peculiar greenish tinge. This is usually obtained at about one-millionth of an atmosphere.

Since the Röntgen effect is evidently due to molecular bombardment, and varies with the degree of the vacuum, it would appear that good experimental work can be conducted, both by ascertaining the best degree of vacuum in tubes containing rarefied air, and by ascertaining whether gases other than air will produce, in such tubes, better results.

It would appear that the Röntgen rays must be either a material propagation or an ethereal propagation.

A material propagation would require either that ordinary matter be projected rectilinearly as a whole along the rays, or that some disturbance in matter is projected along them.

The burden of probability seems to be against the assumption that the Röntgen rays consist of a material propagation, since they not only traverse opaque, dense substances, but also appear to be unaffected by a magnet. Assuming, therefore, that the Röntgen rays are an ethereal propagation, they must either consist of a translatory movement of the ether, or of some disturbance propagated along it. Such a disturbance would, probably, have to be periodic or vibratory. The vibrations might be transverse, or they might be longitudinal to the path of the ray. Physical science is acquainted with transverse ethereal vibrations, such being, in fact, electro-magnetic vibrations, or ordinary light. These vibrations differ in their frequency, and, hence, in their wave lengths, but are not known to differ in their speed through free ether. In the ether within material substances their velocity of propagation is reduced, as is evidenced by their refrangibility. This is true of all known transverse vibra-

tions from the lowest frequency, far below the red, produced by the discharge of a Leyden jar and detected only by electrical methods; through the higher-frequency waves, still in the infra-red and constituting direct heat; throughout the limits of the visible spectrum, and beyond the violet in that frequency which is detectable only by chemical or by electric eyes. The marked characteristics of these transverse vibrations are their refrangibility, their reflectibility and their possibility of interference; characteristics which are all apparently wanting in the Röntgen rays.

It would, therefore, appear that the Röntgen rays are not transverse vibrations of the ether. If they are, they do not appear to lie within the range of frequency hitherto explored, a range extending from about 100,000 to about 1,000,000,000,000,000 (a quadrillion) waves per second. There is reason to believe that if they have a wave length, this wave length is long compared with that of visible light, since they pass through appreciable distances of gross matter, distances measured in centimeters or hundredths of a meter, rather than in microns or millionths of a meter. Such waves would correspond to dark heat waves, in the infra-red.

It is known that ultra-violet light possesses the power of discharging a negatively charged body upon which it falls directly, while, as Prof. J. J. Thomson has discovered, the Röntgen rays can discharge bodies either positively or negatively charged, even while imbedded in a layer of highly insulating material.

Dr. Lodge has shown that when polarised ultra-violet light strikes such a negatively charged polished plate, it is most effective in producing discharge when striking at an angle, instead of perpendicularly, and, consequently, the discharge may, perhaps, be effected by a longitudinal component of the impact. This seems to favor the supposition that the Röntgen rays are longitudinal ethereal vibrations.

The material substances with which we are familiar, and which are capable of transmitting vibrations transversely to the direction of propagation, are also capable of transmitting longitudinal vibrations. The fact that longitudinal

vibrations in the ether have hitherto remained undiscovered has caused no little inconvenience in the framing of hypotheses concerning the action and properties of the ether. If ether resembles material substances, its velocity of propagation for longitudinal vibrations would be much greater than that of its velocity of propagation for transverse vibrations; consequently, for any given frequency of vibration, the wave length would be greater than that of light waves.

Summing up, then, while it is far too early to form a reliable conclusion concerning the nature of the Röntgen rays, such evidence as does exist would appear to favor the theory of longitudinal vibrations in the ether.

Whatever may be the future of the Röntgen rays, so far as their practicable applicability or scientific value is concerned, great praise must be accorded to Professor Röntgen for the exceedingly interesting and important contribution he has made to this branch of molecular physics.

LABORATORY OF HOUSTON & KENNELLY,
FEBRUARY 16, 1896.

DISCUSSION.

DR. A. E. KENNELLY.—Having contributed to the paper of this evening, I have very little to add to what has already been stated in it; but a few remarks upon the possible future of the Röntgen rays may be admissible at the present time.

The future may be regarded from a practical and also from a theoretical point of view. There can be no doubt that the Röntgen rays, which render indirectly visible to the eye the bones and interior tissues of the body, must be of great value to the surgeon, anatomist and biologist. It only remains to strengthen and develop these rays in order to extend their range of application. The rays lie, at present, under the troublesome disability of absence from bending or focussing by reflection or refraction. It may be that indirect means may be employed to overcome this difficulty.

From a theoretical point of view the subject is full of interest. Its investigation cannot fail to increase our knowl-

edge of molecular physics and the physics of the ether. Should the rays prove to be of a nature hitherto unrecognised and unknown, an entirely new channel of communication with the unknown world is opened up. I cannot but believe that the great interest which has been bestowed upon this fascinating subject all over the civilised world indicates more than a mere passing fancy or tribute to the most recent scientific passion, that it points to a general effort on the part of the entire civilised community to become acquainted with the new manifestation of Nature, which has, for years, been clamoring at the doors of our senses for recognition, and that it indicates a consciousness that we have before us a most potent agent to aid us in wresting from Nature her secrets in the invisible domain. We all know that advances in sciences are made in epochs, or wave-like periods of activity. May we not hope that this wave of public interest is one whose crests shall lead us to fortune?

I think it would be most fitting that a vote of thanks should be offered to the scientific worker in Bavaria, whose labors have been so fortunately crowned with success, and I beg to propose that such a vote of thanks be extended to Professor Röntgen, by this meeting, for the interesting and important work which we are discussing this evening.

[This motion was numerously seconded, and, on being put to vote, was adopted unanimously.—THE SECRETARY.]

PROF. ELIHU THOMSON.*—From my experiments it appears that the cathode rays are produced only when the vacuum in the Crookes tube is such that little or no light, other than that arising from fluorescence of the glass, is given out. A degree of exhaustion somewhat higher than this stops the electric discharge, while a somewhat lower vacuum, although giving abundant fluorescent light on the glass walls, gives, also, an illumination of the residual gas in the interior, and no cathode rays.

While using one of my tubes, it was noticed that, during the passage of the discharge, the vacuum continually im-

* Correspondence.

proved, and soon became so high as not to permit the discharge to pass at all. This was doubtless due to the fact that one electrode was of platinum instead of aluminum, and that the platinum was carried from it to the sides of the tube and deposited there as a smoky layer. This finely divided metal absorbed the residual gas and so far completed the exhaustion as to prevent the passage of the discharges, even when of very high potential. In this connection it may be mentioned that the vacuum in an ordinary incandescent lamp commonly improved during the use of the lamp. I have found old, discarded lamps, with worn-out or broken filaments, to have excellent Crookes vacua, and sometimes vacua through which no discharge would pass, while new lamps are rarely to be found with so high exhaustion. The reason of the change in the vacuum in this case is doubtless the absorption of residual gas by the film of carbon or soot deposited gradually on the interior of the bulb in the old lamp.

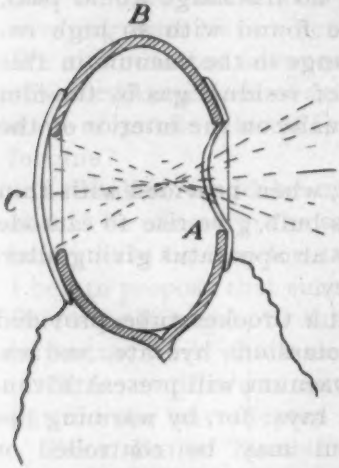
These old lamps may, in fact, when provided with thin aluminum caps outside the glass bulb, give rise to cathode rays when excited inductively by an apparatus giving alternating currents of high frequency.

It appears to me probable that a Crookes tube, provided with a side tube containing potassium hydrate, and exhausted to the highest possible vacuum, will present advantages as a generator of Röntgen rays; for, by warming the hydrate, the degree of vacuum may be controlled or adjusted to that proper for obtaining the best effects.

In order to render it possible to use a large amount of energy in excitation, to the end that the vigor of cathode rays emanating from the apparatus may be made a maximum, it may be possible to construct tubes like the accompanying sketch, where *B* is the vacuum bulb having two openings or windows opposite each other. One of these, as *C*, is capped with a cup of sheet aluminum, cemented on, and having a surface concave to the vacuous interior. The other opening, *A*, would be capped by a very thin cover of aluminum, made, for strength, convex to the interior space. Cap *C* would be made the cathode and *A* the anode. The

rays would converge near *A* within the bulb, then diverge through *A* in passing out into the air. If the whole bulb, except the window *A*, be immersed in oil in a surrounding box, the outside insulation, as well as the cooling of the tube under vigorous excitation, is provided for.

The current best adapted for the development of cathode rays would naturally be a continuous current of from 50,000 to 100,000 volts. Its strength would be made as great as the tube or bulb itself could bear without injury. It is difficult, however, to obtain such currents, while it is very easy to obtain, with simple, cheap apparatus, high-frequency, high-potential alternating currents, which, while not so effective as continuous currents, may be had of any power.



Cathode rays may be detected, as is well known, either by the photographic plate, or by their power of exciting fluorescence. It is conceivable that a simple instrument, such as a blackened tube, having a screen with fluorescent material near one of its open ends, and a sight-hole at the other, might, for practical purposes, be superior to the photographic plate, inasmuch as the exploration desired would be accomplished in a short time and with changing directions of transmission of rays. In this case, of course, no permanent record would be made.

A third method of detection of cathode rays is based on their power to cause discharge of electrified surfaces. An electrified body, connected with an electroscope for indicating its charge, if exposed to the cathode rays, is at once discharged. Recent experiments made at the Massachusetts Institute of Technology have, it is reported, shown that this electrical test will instantaneously detect the rays that have passed through a thick brass plate (about ½ inch) and very heavy plates of vulcanite.

There can be little doubt that means will soon be found for greatly accelerating the making of shadow pictures by cathode rays. Were it possible to produce plates sensitive only to the rays absent in sunlight or ordinary artificial light, it would follow that the taking of the impression could be carried on in a light room with an uncovered plate, and the development of the same carried on without a dark room.

There is yet, of course, much to be learned concerning the real nature of the rays and their relations to ordinary light and heat rays. I incline to the opinion that it is not necessary to consider the cathode rays as differing in kind of ether vibration from light waves, until it is proven that electro-magnetic waves of very high pitch must, of necessity, undergo reflection and refraction at surfaces.

The characteristics of cathode rays appear to be the same in many respects as those of ultra-violet light; both effect chemical decompositions, both cause fluorescence and phosphorescence, and both provoke discharge of negatively-electrified bodies.

May not cathode rays, therefore, be ordinary transverse electro-magnetic waves in the ether, as are light waves, but of such high pitch, relatively thereto, as to be beyond the vibration period of atoms in the molecules of ordinary matter; and that, as a consequence of such high pitch, they can neither be reflected nor refracted, but can travel through bodies in the assumed free ether between the molecules?

It might easily be that, when obstructed by the molecules, absorption takes place from internal refraction or reflection, and absorption would then depend on the amount of matter traversed, as measured by its density and thickness.

It is true that the crude view thus presented may involve changes in our ideas concerning the true causes of ordinary reflection, refraction and dispersion of light. At all events, the new discovery will, in my opinion, become a mighty weapon for attacking anew the problem of the relations between what is called gross matter and the universal ether. We may be able to make one further step towards

unifying the Universe, as when it be shown that in all probability the chemical elements, as we know them, are but modifications in the ether, in somewhat the same way that polymeric bodies depend, in structure, upon modifications of much simpler atomic groupings.

PROF. A. E. DOLBEAR.*—It is remarkable what an amount of photographic activity has been induced by Prof. Röntgen's announcement. The physical laboratories of the world appear to have well-nigh dropped everything else in order to duplicate that work and ring the changes on it, and the experimenters are daily besieged by the multitude of reporters from the daily press, anxious to be the first to describe whatever is done. The utility of it is what gives it its chief interest to the public, as it very properly should, for there is now no foreseeing what great importance it may presently have. To the scientific man, as such, the interpretation of the phenomenon is of first importance, and here the question very properly arises: Is this discovery so radically new as it appears, and is there any reason for assuming the existence and activity of rays or ether waves of a different kind from any heretofore known?

As to the first, it has certainly been known by myself for nearly four years that photographic action would take place in the dark through the activity of waves set up by electric discharges in the air. In 1892, I made a profile of a five-pointed iron star on a photographic surface when the latter was separated from the sparks by the top of a table an inch in thickness, and ordinary light in other ways was excluded. I had expected it from thinking upon the theory of photographic action and of ether waves. I did not publish anything about it at the time, because I came across, somewhere, a scrap saying that the same thing had before been accomplished by another, I do not remember by whom or when. However, I published, in April, 1894, an article in the *Cosmopolitan Magazine*, a copy of which I attach with this,† which

* Correspondence.

† "For a long time it was believed there were three different kinds of ether waves, known as heat, light and actinic rays. The latter were supposed to be the ones that produced the chemical action on photographic plates, while

will show that the knowledge of the fact and the explanation, such as it was, was already in my possession. *Cosmopolitan Magazine* articles have to be prepared two or three months before the date of publication, and that article was written more than two years ago.

There was nothing said about X rays, or cathode rays, for the very good reason that, so far as my experiments

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light consisted of rays of a different kind, capable of affecting the eye. It was discovered, however, that the same rays which can produce vision can also heat a body, and also do photographic work; and what any ray can do depends upon the kind of matter it falls upon, so that all rays have similar characteristic properties. This discovery makes it plain that there is no peculiar kind of ether waves which can be called light, as distinguished from other kinds of ether waves. What is called light is a physiological phenomenon, and has no existence apart from eyes. So well assured is this, that the serious proposal is made to banish the word 'light' from physics.

"The sensitive coating upon a photographic plate is an unstable chemical compound, which may be broken up by mechanical pressure, by heat, or by ether waves. The proper wave length for a given plate depends upon the nature of its surface. The tanning of the skin, the darkening of newly laid shingles, the coloring upon apples and other fruit, is a photographic process, as can be shown by shielding them from the sun's rays.

"It has long been known by photographers that pictures may be taken with ether waves much too long to be seen by the eye, if some other substances are used in place of the simple silver salts in common use.

"Since it has been shown that ether waves of all lengths have an electromagnetic origin, it has been apparent that all the effects of light can be duplicated with suitable electric apparatus. Lay a coin like a half-dollar on a plate of glass, and let a few sparks from an electric machine fall on it. Remove the coin and the glass surface will not appear to have been affected; but if it be breathed on, the image of the coin will at once be seen, and that it is really engraved on the glass surface is evident, for it will not easily rub off. If a piece of photographic paper takes the place of the glass, it will have the imprint of the coin made upon it. It is not needful to have the sparks fall upon the coin, for, if it be enclosed in a dark box brought near to an electric machine having short sparks passing between its knobs, the ether waves set up by the latter will be sufficiently short to affect the photographic surface, which may be developed afterwards in the ordinary way.

"So it is actually possible to take a photograph of an object in absolute darkness with the ether waves set up by working an electric machine. Not much has yet been done in this direction, but it is a new clew to chemical possibilities, and one may confidently look forward to the time when the qualities and colors of surfaces of many things will be changed to suit the taste by an application of electric waves of suitable length to bring about the proper chemical reactions, and an electric machine may become a necessary adjunct to the apparatus of the photographer."—*Cosmopolitan Magazine, April, 1894*

went, only ordinary means and apparatus had been employed, and there had been found no necessity for assuming that the work done necessitated other kinds of waves than such as I supposed myself to employ. Dr. W. J. Morton, of New York, and others, have lately reported similar experiments, which corroborate the proposition that vacuum tubes, as such, have little to do with the phenomenon.

As to what was generally known about the fundamental principles, it may be said that it was not new to photograph by waves either too short or too long to be visible. Photography can go on wherever fluorescence is possible, and ultra-violet waves have long been known to be effective for that purpose. Dr. Draper, fifty or more years ago, got photographic effects in the region beyond the red; and Captain Abney, in England, long ago photographed the whole spectrum a long way above and below the visible part. Hence, photographing with invisible rays, either long or short, is not new.

After Hertz's work was published everyone has known that ether waves set up by electric action were initiated in the discharges of Leyden jars and condensers in general, and that the wave length depended on their capacity; also, that such discharges always set up phosphorescent and fluorescent action in gases and solids; that is, relatively long waves were capable of producing phosphorescence.

That such waves, invisible to the eye, were capable of passing easily through bodies opaque to visible or certain definite wave lengths, has been known for many years. Iodine in bisulphide of carbon is opaque to the eye, but very transparent to other waves, and Tyndall raised bodies to incandescence by such passed through that medium. He called the phenomenon *calorescence*. Afterwards, Bell showed that vulcanite was similarly transparent, while Hertz proved that stones, wood, etc., were transparent to waves set up by electric discharges.

All this shows that the data for supposing that such shadow photography as we now have, even to the distinctions between bone, muscle and bullet, were common knowledge.

What Röntgen did was to take a picture of his hand, showing the bones. If he had taken a picture in a similar way of a coin only, the interest in the experiment would have been small until some one had done *that particular thing*. It is that which has pushed the matter to its prominence, and rightfully so, for it has given photography a new field, which, though lying close at hand before, had not been entered on the physiological side, and which promises practical applications of great value.

As to the interpretation that may properly be given, or attempted, it may be too early to do more than believe very gently. It is evident that a phenomenon involving phosphorescence, fluorescence, photography, transparency and opacity, long and short waves, their origins and properties, is tolerably complicated; but for myself, I should say that every effort should be made to find the explanation with the transverse waves we know, and take the longitudinal wave only as the last resort. When one reflects upon the well-known phenomenon, fluorescence, that it is not only the transforming of short waves to longer ones, as in eosin, but also the transforming of long waves into shorter ones, as happens with chlorophane, which changes waves much longer than the red rays into emerald-green waves. Hence, it is entirely within proper bounds to expect that rays made too long to be appreciably refracted can act upon a phosphorescent body so as to produce waves capable of doing photographic work.

Again, there does not appear to be any good reason for thinking that an electric discharge can produce among atoms and molecules particular movements and resulting waves different in kind from other agencies, say heat, for instance; and if so, the same rays found in electric discharges in the air, and from Crookes tubes, are to be found in other sources of light as well, differing perhaps in degree, but not otherwise.

Dr. Joseph W. Richards.*—Since the shadow pictures are made through substances ordinarily considered opaque,

*Correspondence.

it has been assumed that the *light* rays have nothing to do with casting the shadow. It should be remembered, however, that substances are only *relatively* opaque. Strong sunlight shows the bloodvessels in the ear, even the veins in the hand. Even metals are translucent if in thin enough films. Magnetic iron oxide, the most opaque of all substances, is translucent when crystallising between leaves of mica. There is no substance known to science which is absolutely opaque, even to ordinary light rays.

We know that heat rays can pass through substances opaque to ordinary light. Can we not readily imagine a *thermo*-graph, made on a plate very sensitive to heat rays, placed behind a screen cutting off ordinary light? Substances would cast shadows on such a plate in proportion to their transparency or opacity to radiant heat.

Coming now to the X rays, I believe they act on an analogous principle. It is said that they are difficult of refraction. If this is so, may it not be because they are so far below the ultra-red rays that their index is so small as to have escaped observation? The very long waves of Dr. Hertz passed through wood, etc., like the X rays, but he refracted them by a huge prism of pitch. There seems to me to be many points of resemblance between Dr. Hertz's rays and these X rays.

Metals have the highest known indices of refraction for light rays. Allow me to suggest that *metallic* lenses (as of aluminum) may enable the X rays to be refracted and focussed.

Glass is said to intercept or weaken the X rays. Possibly the glass bulb of the Crookes tube, therefore, weakens the effect. If the bulb were made of celluloid, or some other available material transparent to the rays, heightened effects could be obtained.

A rigid search will probably result in the discovery of films more sensitive to these X rays than even our most instantaneous light plates. It is not only possible, but even probable, that there exist such compounds, the use of which would give us *quick* plates for the X rays.

There is no reason why the X rays cannot be generated

on a much greater scale than heretofore, and thus more striking results be obtained. Experiments with other metals than aluminum in the discs may result in showing that the effects are modified by the kind of electrode emitting the rays.

PROF. GEO. A. HOADLEY.—Having seen several statements in the newspapers quite recently that Röntgen photographs could be obtained in the electrostatic field of a Holtz machine, I have thought it might be of interest to show that the effects thus produced are not due to the Röntgen rays.

The first two lantern slides, which I show you, were made from negatives obtained by placing a coin upon a photographic plate, wrapping the two in several thicknesses of black paper, and placing them between the knobs of the machine, when they are at the proper distance to produce the brush discharge.

At all points where the coin was in contact with the plate, the effect of the discharge is seen showing the lettering, figures and date, while around the edge is a rim of minute radiating lines.

The third slide shows the effect of the condenser spark on both sides of the plate, the one on the rear side being much less distinct than the one on the film.

MR. W. N. JENNINGS.—I had the honor of showing, in this hall, six years ago, the image of a silver dollar, made in precisely the same way as those now shown; also a spark taken on the plate direct. These photographs I also used in connection with my lecture before the Institute last April, and explained fully, at the time, how the pictures were produced. I make this statement now for Professor Hoadley's information, and merely to place the matter on record.

MR. JOHN CARBUTT.—Naturally, the announcement of Professor Röntgen's discovery of photographing the invisible, with what he terms X rays, attracted my attention, the more so as I saw that a new field had been opened for the use of dry plates. The length of exposure required particularly interested me, and I therefore commenced experiments to produce, if possible, a plate that should be

more sensitive to these X rays than the ordinary rapid plate. The tests made on these new plates which I have prepared have enabled me to reduce the exposure from one hour to twenty minutes, when making a shadowgraph of the human hand. Professor Goodspeed, of the University of

Copy of picture made with one of Carbutt's Special "Röntgen Ray" Plates (exposure, 21 minutes). 1–2, flat steel keys $\frac{1}{16}$ inch thick; 3, leather purse with steel clasp, containing coins and disk of aluminum; 4, sheet of glass; 5, aluminum rod ¼ inch thick; 6, imitation diamond pin.

Pennsylvania, kindly placed at my disposal the Crookes tube and coil with which he had made his experiments. Placed on the box holding the X ray dry plate was a purse containing a number of coins, including a disc of aluminum;

alongside of the purse were two flat steel keys; below these a piece of ordinary window glass; in the center, beside this, an imitation diamond pin; and, on the lower right-hand corner, a piece of rod aluminum. Two exposures were made, one of twenty-one minutes and the other thirty minutes; the negatives were at once developed, using my "J. C. Tabloid Developer." The plates developed up in the normal time usual to a fully exposed plate, and the results were pronounced by Professors Goodspeed and Richardson superior to any they had obtained, even with a much longer exposure. The transparency now on the screen shows that the X rays obliterated the leather of the purse and passed through the aluminum disc and the piece of glass in about the same ratio.

PROF. CHAS. F. HIMES.—I made some experiments with Crookes tubes and a coil giving 7-inch sparks, but with negative results, which I attributed to the absence of the peculiar rays from the light I employed. Thereupon, I turned to sunlight as possibly containing some similar form of energy transmissible through substances opaque to visible light, and made the following experiment: A thick piece of ebonite was placed in an ordinary photographic plate-holder, and upon it a Carbutt "Eclipse" plate, separated from the ebonite by strips of heavy cardboard. Several pieces of black paper were placed upon the plate, and then the felt-covered hinged back was fastened in. The ebonite was then exposed to bright sunlight, partially covered with a ring of sheet brass having a central circular aperture of about $\frac{3}{4}$ inch. After an exposure of twenty minutes, prolonged development gave no apparent result. An extreme exposure of three hours and a half was then made at midday in bright sunshine, and less prolonged development gave the unexpected result of a dark ring on a light ground with a light center, or a positive. Regarding this as a reversal by over-exposure, another exposure of forty-five minutes was made, which, upon development, gave a negative or light ring on dark ground with dark center.

I do not say that Röntgen rays are involved, but this experiment proves at least this much—that there is a form of

energy in the sunlight, transmissible through ebonite, and, perhaps, through other opaque substances, and which, perhaps, is also present in other sources of light. I have not been able, however, to detect them in magnesium light. As the plates were separated from each other by the thickness of the cardboards, and the temperature at the time was near 0° F., the result seemed only explicable by the transmission of the rays by the vulcanite. A similar exposure to rays from a warm iron plate gave no developable effect, although the vulcanite became sensibly warm.

It will be *apropos* here to recall the oft-cited experiment of Abney, of photographing with the rays from a tea-kettle as having some interest in connection with the subject of this evening's paper.

The photographs so-called were simply shadowgraphs. A card with perforations was held above the sensitive plate, and a hot tea-kettle placed above the card, and, after a short exposure, the plate, upon development, showed spots of the shape of the perforations. But a much more remarkable experiment, made by this investigator at the same time, more than ten years ago, was the photographing of the carbon points of an arc light through a piece of vulcanite with an ordinary lens, in about thirty seconds.

I regard as the most suggestive feature in connection with these experiments, that Abney was illustrating and emphasising the possibility of imparting peculiar kinds of sensitiveness to bromide of silver by suitable treatment, and thus of obtaining photographs by ultra rays, and that he was calling attention to the particular modification he had produced. The transmissibility of rays through vulcanite was an incident. It seems to me that much of the progress of the new photography must lie in the direction of the production of films peculiarly sensitive to these so-called X rays. All recent progress in photography has been in the direction of the preparation of films responsive to any peculiar demand, and it is a matter of great gratification to learn that Mr. Carbutt has already recognised this new field for his activity, and that there is every reason to hope, from his known success in meeting all demands hitherto made upon

him, and his character as an indefatigable experimenter, that he will be able soon to furnish us X ray plates that will permit the use of sources of light more readily available.

Referring to my own unsuccessful experiments with the Crookes tube, I should state that such a result ought to have been anticipated. The tube employed was the so-called shadow tube of the set, and was an excellent one for the purpose for which it was designed, but the cross of aluminum, which produced a shadow on the fluorescent ground of the tube, almost constituted a test for effective rays and indicated the almost complete absence of any that would pass through aluminum under the conditions present in the tube. Other shadow tubes giving less perfect shadows might furnish more of the active rays.

MR. JAMES WILSON.—The paper just read has described very thoroughly the effects and peculiarities of the Röntgen or X rays. A description of the Crookes tube, in which these rays are generated, might aid a little in the discussion of the mystery.

In 1884, when the Franklin Institute held its great Electrical Exhibition, Mr. Chas. H. Richardson and myself had the care of the exhibit of electrical and scientific instruments of Queen & Co. In that space we had a dark room to show Geissler and Crookes vacuum tubes. This experience and years of handling and testing Crookes tubes, when received and sold, enabled us to become more or less familiar with Professor Crookes' theories of "Radiant Matter," or, as he termed it "The Fourth State of Matter."

I, therefore, venture to offer a theory that will partially explain the cause and some of the peculiarities of the mysterious X rays, that have been so ably treated in the paper just presented by Drs. Houston and Kennelly. In December, 1878, Dr. Wm. Crookes described before the Royal Society of Great Britain his various experiments, to prove that there is a state of matter beyond the gaseous, in which the molecules of matter, having so much more space to move freely, have their mutual attractions altered, thereby giving the same chemical material new physical properties, making it as much different from a gas as a gas differs from a liquid,

or a liquid from a solid. For example, two atoms of hydrogen and one atom of oxygen combined chemically form one molecule of water. These water molecules may be arranged together in the form of solid ice, liquid water, or gaseous steam, the difference being one of pressure, or temperature, or both.

In a gas the molecules can move freely among themselves, having lost much of their mutual attraction or cohesion.

At the ordinary pressure of the atmosphere, 15 pounds per square inch, if a vibration or motion is imparted to a molecule of a gas, it can move only an exceedingly small distance without striking another molecule. Dr. Crookes found that, when the pressure was removed, each molecule could then move a considerable distance without striking another; and that, under the influence of an electrical discharge or vibration, they acted differently from when in the gaseous state.

When a glass tube, having metal electrodes sealed through the glass, is partly exhausted, and placed near a Holtz glass-plate electrical machine, or in the secondary or tertiary circuit of an induction coil in operation (potential of 20,000 to 50,000 volts), there is a stream of light, usually violet, from one electrode to the other. At about $\frac{1}{1000}$ of an atmosphere exhaustion, the stream of light seems broken into numerous stratifications of light and darkness, and although the negative end of the tube is always brightest, there is a space close to the metal of the negative electrode where there is no light. Dr. Crookes explained the dark spaces between the stratifications and around the negative pole as the "*mean free path of the molecules*;" *i. e.*, the average distance that a molecule could move without a collision with another molecule.

At low exhaustions, no matter how the tube be bent, the discharge or stream of light goes from one electrode to the other, and if the tube be brought near a magnet, the stream of light is attracted or repelled, as though it were a conductor carrying a current of electricity. If the exhaustion be increased, the dark space about the negative

electrode grows larger, until it fills the entire tube. At an exhaustion of about the $\frac{1}{1000000}$ of an atmosphere, there is no stream of light from one electrode to the other. The stream of light meant collision of molecules; now the molecules can move the entire length of the tube without collision; where they strike the glass, they set the *molecules* of the glass into vibration, producing a fluorescent light, the color depending on the composition of the glass. The molecules move in straight lines from the surface of the negative electrode (cathode), no matter where the positive pole be placed. If the glass tube be curved or bent, the flying molecules will not turn the corner. If the negative electrode, or cathode, be in the form of a flat plate, the molecules will fly from it in parallel lines; if it be concave, like a saucer, they will fly from it to a focus; if there be two cathodes, the streams of molecules from each repel each other. Dr. Crookes' explanation is, that as the molecules floating in space come in contact with the electrically-charged plate (cathode), each one becomes similarly charged and is repelled, and, there being no resistance to their motion, they fly with great velocity. A few are deflected by collision with other molecules coming slowly toward the plate. Others strike the glass without collision with other molecules, thus producing the greatest effect on the glass at one spot directly opposite the negative electrode. If any substance be placed in the path of the molecules between the negative electrode and the glass, a shadow of the substance will appear on the glass. If the substance be capable of fluorescence, it will glow with a characteristic color, when placed in the path of the molecules—a diamond glowing with a light equal to that of a candle. If the cathode be made concave, and a piece of platinum foil be placed at the focal point, it will be heated white-hot and fused, showing that the energy of the bombarding molecules can be changed into heat. If a magnet be brought near the tube, the focal point can be deflected, and a hole melted in the tube. If a light wheel with vanes be placed in the tube, and the flying molecules allowed to strike against the vanes, the wheel will revolve rapidly. These flying molecules, whose direc-

tion depends so much on the form of the negative electrode, have been called *cathode rays.* The X or unknown rays, that are capable of affecting a sensitive photographic plate through substances that are opaque to light, seem to start from the fluorescent surface of the glass, the greatest effect being produced on the photographic plate, when this is placed opposite the part of the glass subject to the greatest bombardment. From the fact that the rays inside the tube can be deflected by a magnet, and the X or unknown rays outside the tube cannot be so deflected, it is assumed that there are no X rays inside the tube, and, of course, there are no cathode rays outside of the tube. X rays seem to differ from all other forms of energy, except in one particular—they act on a photographic plate like light waves.

The question is, what are they? A ray of light is affected by a powerful magnetic field. The paper of the evening explains that the principal difference between Lenard rays and Röntgen or X rays is, that the Lenard rays are affected by a magnetic field, and the Röntgen rays are not. The suggestion that they are longitudinal vibrations in the ether only adds to the mystery, because the existence of the *ether* itself has never been proven, it being itself merely an imaginary X quantity adopted to supply the missing link needed to make the wave theory of light plausible.

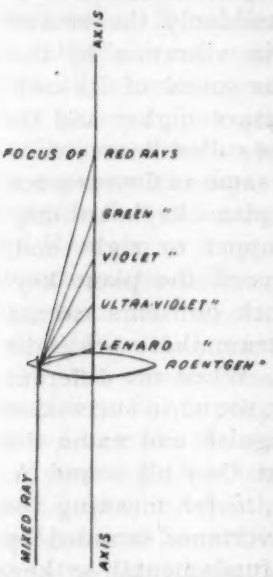
Accepting Dr. Crookes' theory of what happens inside the Crookes' tube, I hold with those who think that the Röntgen and Lenard rays are both similar to light rays, and are ultra-violet light, and that they bear the same relation to ordinary light that harmonics or overtones do to a fundamental sound. The accepted theory of fluorescence is, that the fluorescing substance receives waves of a certain rate of vibration, and transforms them into waves of a different rate of vibration, usually changing short, rapid waves, into longer, slower waves, and, in some instances, the reverse. If a beam of light from a slit be passed through a prism, and the spectrum thrown on the wall, we can readily note about where the red begins and the violet ends. If a piece of paper painted with a solution of quinine be placed beyond where the violet ends, what before was darkness

now appears light; part of the invisible ultra-violet light has been made visible, because the quinine changed the rate of vibration low enough to bring it into the range of what our eyes are capable of seeing. If we had eyes adjusted to be sensitive to these rapid rates of vibration, we might be able to see the ultra-violet light without the use of quinine, or any fluorescing substance, and even X rays might be visible.

To make a comparison with sound, for the purpose of illustration, go to a piano and hold a key down softly without striking the string, then strike suddenly the octave higher; the first string will be set in vibration by the second, and will give a mixture of the sound of its own fundamental tone, and that of the octave higher and its overtones. This phenomenon might be called fluorescence in sound, the relative effect being the same as fluorescence in light. The left or lower end of the piano keyboard may be compared with the red, and the upper or right end, with the violet, of the spectrum. Beyond the piano keyboard limits, there are tones to which our ears cannot respond in unison; beyond the spectrum there are light vibrations our eyes cannot appreciate. When the different instruments in an orchestra, in tuning, sound in succession the key-note of A, it is easy to distinguish and name the instrument that makes the sound, yet they all sound A. The difference is called, in acoustics, *timbre*, meaning the difference in number and particular overtones sounded by each instrument in addition to the fundamental or key-note.

Most large orchestras have two or three kettle-drums, a membrane screwed over a copper kettle and tuned to give one particular fundamental note only. If we drop pebbles or sand on it, or if we could provide a membrane that would not absorb water and stretch out of tune, we could place it out in a shower of rain and get the musical note and its overtones, the same as if pounded with drumsticks. The action of the Crookes tube and the kettle-drum may be compared. The bombarding molecules of air strike the glass as the globules of rain strike the membrane of the drum; the membrane is

tuned to one fundamental note, and has its overtones or harmonics, one, two, three, five, etc., octaves higher, with some fifths and thirds, all mixed, together giving the characteristic sound of a drum. The glass molecules are tuned, so to speak, in the case of the Crookes tube made of ordinary German glass, to the key of G, or green light, and, when set in vibration by the bombarding air molecules, give forth the fundamental green which we see. The overtones or harmonics being some octaves, thirds and fifths above, are Lenard and Röntgen rays of ultra-violet light, Röntgen or X rays being possibly some octaves higher than Lenard rays. The reason that aluminum gives off X rays apparently without fluorescence may be due to the fact that the molecular fundamental light tone of aluminum may be itself beyond the violet; that is, its fluorescence is beyond our eye limit.



If light be a transverse vibration of molecules, there is no reason why wave motion should stop abruptly at violet, or an octave beyond violet light. Mathematically considered, wave motion should continue until it merged into a straight line or infinity. We might assume that when transverse vibrations became exceedingly small they would merge into longitudinal vibrations, which would be represented by a straight line when compared with a wavy line, representing transverse vibrations. The ultra-violet or harmonic theory may also explain why they have not been refracted. (See accompanying sketch.)

The focus of the red rays, passing through a lens or prism, are always refracted farthest from the lens; the violet rays are brought to a focus much nearer the glass; the ultra-violet would be still nearer, and the Lenard and Röntgen rays would possibly not get out of the glass; they would be absorbed. If a very thin lens of long focus were tried with

sufficient force of rays to penetrate to the focal distance in air, some Röntgen rays might be found between the violet focus and the lens; or, if a lens were made of a very light material, whose density and composition would have nearly the same relation to X rays that glass or water has to light waves, the X rays might be refracted. Air seems to obstruct the passage of X rays, which means that their energy is absorbed in trying to start the air molecules vibrating at an X ray rate, or some octaves lower; therefore, any substance placed around the Crookes tube, which is capable of vibrating at an X ray rate, or an octave near it, should transmit X rays freely.

If a Crookes tube be made, similar to the form in the communication of Prof. Elihu Thomson, and on the side of it from which the X rays are to emerge another lens-form tube be blown—this extra lens-form chamber to have a Geissler-tube vacuum—it is probable that the rays would be partly refracted, sufficient to concentrate them.

From what we know of the sun as a source of energy—of heat, light and electricity—Röntgen rays are, undoubtedly, shed upon us in great quantity; and as the air obstructs and absorbs some of those given off by the Crookes tube, possibly most of the X rays from the sun are absorbed before they reach the earth. A fluorescing substance may yet be discovered that will harmonise more readily with X ray vibrations from the sun than anything yet known, reducing their rate of vibration sufficiently near that of violet light, after passing through substances opaque to ordinary light, to permit us to see them. There will then be no need of Crookes tubes. The sun will do the part of the induction coil and cathode, the higher atmosphere will be similar to the interior of the Crookes tube, and the lower atmosphere will act the part of the fluorescing glass. We will try to do the rest.

If it can be proven that X rays are vibrations similar to those of ultra-violet light, but more rapid, the name X rays, instead of being the algebraic sign for the *unknown*, may mean that their proper place in the spectrum is where the Frauenhofer line *X* would be; line *A* being in the extreme

red end, *D* in the yellow, *E* in the green, *H* in the violet, *I*, *J*, *K*, and so on to *X*, beyond the violet.

The assumption that X rays are longitudinal vibrations in the ether may be harmonised with the ultra-violet light theory, by premising that X rays are *caused* by longitudinal vibrations in the ether; for, if this imaginary ether be perfectly homogeneous, filling all space, the vibrations started by the sun may be longitudinal until they reach our atmosphere, where they may be transformed into other forms of vibration, electric, heat, light, and X or Röntgen vibrations.

Of course, statements like these, made in an extemporaneous discussion of such a profound scientific mystery, must be regarded merely as suggestions. Practical investigators will, I believe, soon discover new facts sufficient to establish a theory that can be proven experimentally, and enable mankind to more thoroughly utilise this latent force of Nature.

MR. A. E. OUTERBRIDGE, JR.—Mr. President, I came to this overflowing meeting, only to look, to listen, and to learn something of this strange discovery, respecting the precise nature of which there is at present so much speculation and vagueness of ideas.

I did not expect to be able to contribute any information to this symposium; but while listening to the address of Drs. Houston and Kennelly, my mind reverted to a memorable occasion, nearly eleven years ago (which some of those now present can, no doubt, recall), when the famous physicist, Sir William Thomson, now Lord Kelvin, during the electrical exhibition held under the auspices of the Franklin Institute, gave, at the Academy of Music, a most enlightening lecture upon "the wave theory of light."

This address made a profound impression upon my mind, and gave me a new intellectual comprehension of the scientist's mathematical conception of the nature of light waves, propagated through the luminiferous ether, as distinguished from sound waves, travelling through the air, and also indicated a possible though unknown analogy. I can vividly recall in my mind's eye, at this instant, the moving diagram upon the screen, exhibiting these two distinct forms of wave motion, and although I cannot now

repeat the precise words then used by the lecturer, the substance of his remarks was, as I recall them, that the propagation of waves of light through the ether was explainable only on the theory of *transverse* displacement; the propagation of sound waves, on the other hand, is due to alternate condensation and rarefaction of the grosser air, rarefaction succeeding condensation at intervals, of course, of half the wave lengths, making longitudinal waves.

Then—becoming enthusiastic over his subject—forgetting for the moment the so-called "popular" nature of his address and his audience—discarding his written notes—he gave a momentary glimpse, to those who could keenly and understandingly follow his intellectual flight into these higher ethereal regions of the inmost (perhaps prophetic) thought of the astute philosopher; and he exclaimed somewhat as follows:

"What is this thing we call the luminiferous ether?

"It is the one thing in all nature we are sure of; that is, the reality and the substantiality of the luminiferous ether.

"I have shown you the diagram of transverse waves of light; may there not also be *longitudinal* waves in this ether, having unknown powers, of which, at present, we have no conception? I am not prepared to say that it is so—this is little more than a scientific dream of mine; yet we cannot say that the luminiferous ether is *not* capable of longitudinal vibration; indeed, I cannot conceive of its incapability, if it be in the least degree compressible; and, while I do not venture to make an assertion at this moment that we will have a new development of force in the future that will be explainable on the theory of longitudinal vibrations of the ether, I think some of us now present may live to see that, though I may not."

While I believe that I have, in the main, correctly recalled these fleeting expressions, unfortunately not recorded at the time, you must not, of course, hold Lord Kelvin responsible for the accuracy of my unaided memory.

This all-pervading (although purely hypothetical) luminiferous ether, an imponderable medium, unaffected by

gravity, so far as we know, having great rigidity and elasticity, the only conceivable material connecting link between ourselves and distant worlds, is now regarded by modern philosophers *as the key-note, or the fundamental principle, or genesis of all matter;* indeed, the greatest leaders of thought in this realm of pure science no longer hesitate to attribute all the varying properties of matter to "motion of molecules" of this universal medium. Lord Kelvin said, for example: "What we call matter may be only the rotating portions of something which fills the whole of space, *i.e.*, vortex motion of an everywhere-present fluid," and in his famous address at the Montreal meeting of the British Association* some years ago, he still further elaborated the same thought, and said: "It is scarcely possible to help anticipating, in idea, the arrival at a complete theory of matter in which all its properties will be seen to be merely attributes of motion."

At the present moment we are lost in a sea of speculation, regarding the nature of the new "X ray" shadowgraphs of Professor Röntgen, and in almost a nervous condition of excitement as to the possible future developments; but we have been led by these theoretical and mathematical studies up to a level of comprehension of their possibility.

A word in concluding may serve to explain Professor Himes' doubt as to the presence of X rays in the Crookes tube. He asks: If aluminum is transparent to these rays, why is a shadow cast upon the end of a tube by an aluminum cross interposed in the path of the cathode rays? I think an explanation is this: Aluminum is only comparatively, not absolutely, transparent to these rays. This is proven by the shadowgraphs of aluminum coins thrown upon the screen a few moments ago. Had the metal been *perfectly* transparent, the faint silhouette of the coin would not have appeared at all upon the sensitised plate.

The more intense fluorescent light at the end of the tube in those portions exposed to the full glare of the cathode rays (or to the unshielded bombardment of molecules) would

*Steps toward a Kinetic Theory of Matter. Proceedings B. A., 1884.

naturally disguise any fainter fluorescence which might otherwise be visible within the shadow of the cross, due to the impingement, within this penumbra, of fewer molecules; or, in simpler words, to the partial leaking through the aluminum cross of cathode or X rays.

The cross is pivoted on a hinge, and when it is thrown down, so that the entire end of the bulb is exposed to the cathode rays, behold! the image of a luminous cross appears on the glass bulb, shining much brighter than the surrounding portions of the fluorescent glass. This is commonly explained, by Professor Crookes and others, on the theory of "fatigue." May it not be due to normal fluorescence of the glass under full exposure, plus the fainter fluorescence caused by leakage of cathode rays, due to partial transparency or permeability of the aluminum?

The gradual fading of the cross from view is explicable upon either theory.

PROF. M. B. SNYDER.—It was far from my intention to have anything to say at this time regarding the important discovery of the action of these rays; but since I have been so cordially invited to participate in this discussion, a few observations may be allowable. The chief interest of Röntgen's admirable discovery lies, it seems to me, not in the proposed practical applications, however important those may come to be, but rather in the bearing it may have in forwarding more accurate theoretical conceptions of the whole question of radiant energy. While it is not desirable, in this discussion, to go into detail concerning any opinion regarding the theory of these phenomena, I may say that I have no manner of doubt that these Röntgen radiations do not require the supposition of the character of longitudinal vibrations. They are, in all probability, but a part of the vast series of electro-magnetic vibrations with which we are already acquainted in the magnetic, heat and light spectra. This would, of course, give them the character of transverse waves. The longitudinal vibration of the ether must be reserved, it seems to me, for gravitation itself. We do not, unfortunately, at the present time, possess a mechanical theory of the ether that is even fairly satisfactory, but

the indications, as developed by Lord Kelvin and others, suggest that there is nothing yet known that should prevent us from regarding these rays as a part of the vast electromagnetic gamut. Their refraction, reflection, and even polarisation, would then be a probable result of the future experiments.

An important element in the Röntgen experiment seems to be the transformation of energy that takes place at the surface of the tube, and this has suggested the reflection that we are in all likelihood laying too slight an emphasis upon the changes that take place in the solar radiations within our own atmosphere, changes that may be analogous to those we see in this experiment. The radiant energy of the sun is of one character in space, and of another character within our own atmosphere, just as the action within the Crookes tube is one thing, and that without it another. So, although this is not the time to moot and discuss the mechanical conceptions we should assume, it is, I hope, not beside the question to insist that, however fascinating the applications may be, it is in no less degree fascinating to attempt to provide for this new discovery a proper place in relation to the accepted scientific conceptions. It is even possible that the world-wide interest aroused by the experiments of Röntgen may expend itself in working out a truer conception of radiant energy than has as yet been at all deemed possible.

PROF. GEO. F. STRADLING.—From what I have been able to learn on the subject of this evening's paper, the observers disagree on some points. Professor Frost, of Dartmouth College, for example, finds that his rays found no difficulty in passing through crossed tourmalines; while Dr. H. C. Richards, of the University of Pennsylvania, finds that tourmaline is quite opaque to his rays. Röntgen regards aluminum as a good transmitter, while Professor Frost finds it to transmit poorly. May it not be that there is some marked difference in the rays, at present the subject of so much discussion and speculation? Perhaps one experimenter is using Lenard rays, the other Röntgen rays.

MR. CHAS. H. RICHARDSON.—Mr. President, I would like

to ask Prof. Houston a question. When using the Crookes tube connected, as he describes, to a Tesla high-frequency coil, which is connected to a Ruhmkorff induction coil, the latter charged from the street alternating current, is one pole or electrode distinctly negative, the same as when the Crookes tube is directly connected to the Ruhmkorff coil and energised from a battery, or do both poles give the cathode ray?

PROF. HOUSTON.—Each pole of the Crookes tube gives a cathode ray.

MR. RICHARDSON.—That is, the alternations are so rapid that each electrode appears as if it were the negative electrode?

PROF. HOUSTON.—Yes; there are two fluorescent surfaces of the tube, one due to each electrode.

MR. RICHARDSON.—Mr. President, in conclusion, I would like to make a statement. In one of the letters read to-night, I think from Prof. Thomson, is a suggestion of a visual apparatus for use with the X rays, consisting of a dark tube coated inside with some fluorescent substance which could be placed to the eye and directed towards the Crookes tube.

Such a tube has already been designed and made by Professor Magie, of Princeton University. The rough model consisted of one section of a spy-glass, with the lens removed, and one end covered with a piece of black card-board. The inner surface of this card-board disc was coated with barium-platino-cyanide.

When this apparatus was held to the eye and directed towards the sun, no light could be seen in it; but if pointed towards the active Crookes tube and held close to it, the card across the lower end lighted up with a light green hue, and any object opaque to the X rays, held between this tube and the Crookes tube, would cast a black shadow on the card.

I saw the outline of a key and also of the human finger. A gentleman present said he could see the outlines of the bones inside of the outlines of the finger, but I could only detect a heavier shadow in the center of the finger.

DR. KENNELLY.—I have listened, with great pleasure and interest, to the remarks that have been read this evening from different parts of the country, and made by different members of this audience. I think it would be evident, from the differences of opinion manifested in these remarks, that our present knowledge of the nature of Röntgen rays is very limited. I think, however, there can be no doubt that, with so many able workers in different parts of the world, engaged upon the investigation of these rays, it will not be very long before our knowledge of them will be greatly extended. The surprising feature about these rays is that they are produced under conditions which must have been present at any time during the last ten years to nearly every experimentalist in electricity. Nearly everyone having an induction coil and Crookes tube at his disposal has made those marvelous experiments by which Crookes has manifested the behavior of the cathode rays. Throughout all the trials and experiments of this sort, which have been made in this and other countries since the advent of the Crookes tube, these Röntgen rays have, in all probability, been developed, and have been patiently waiting for discovery. It is those things which lie immediately before our eyes that are often so hard to find.

Stated Meeting, December 18, 1895.

MR. JOS. M. WILSON, President, in the chair.

AUTOMOBILE VEHICLES.

BY PEDRO G. SALOM.

The subject of automobile vehicles is almost as old as the locomotive, and, indeed, may be said to be contemporaneous with the locomotive, as all automobile vehicles are, in the truest sense, locomotives. But the fundamental distinction between the two is that one is designed for operating on a rail, while the other is designed for operating on a road or pavement. With the advent of the steam engine, it was natural to suppose that the question of moving

vehicles would receive consideration. And so it did; for, as early as 1827, Goldsworthy Gurney built and operated a motor vehicle run by a steam engine, a picture of which I will show you later on the screen.

The subject has been revived by the marvelous results obtained in France, in the two contests which have recently been held there. In the last race, between Paris and Bordeaux and return, a motor vehicle, equipped with a Daimler motor, covered the distance of 750 miles in a little over forty-eight hours, at an average speed, including stops, of nearly 16 miles per hour.

I may be pardoned for reading a short sketch by John T. Bramhall, in *Leslie's Weekly* of December 19, 1895, which, in a charming and concise form, gives a description of the early attempts to introduce automobile vehicles:

"It is a curious circumstance that the horseless carriage is one of the most ancient of ideas. Homer tells us how, when Thetis went to Vulcan with her prayer for a shield for Achilles, she found the lame architect hard at work, bathed in sweat from the heat of his forges.

> "That day no common task his labor claimed,
> Full twenty tripods for his hall he framed,
> That, placed on living wheels of massy gold
> (Wondrous to tell), instinct with spirit, rolled
> From place to place, around the bless'd abodes,
> Self-moved, obedient to the beck of gods."

Milton speaks of

> "* * * * the barren plains
> Of Sericana, where Chineses drive
> With sails and wind their canny wagons light."

The Earl of Worcester, among his "century of inventions"—inventions which, like Keely's motor, always lacked the one prime element of practical success—may have had an automobile carriage. But if he had, it was in the same uncompleted state as the tripods of Vulcan. It never "went." It is certain, however, that, in 1759, Dr. Robinson called the attention of Watt to the possibility of constructing a carriage to be driven by a steam engine, and ten years later, Cugnot, a French army officer, rigged up a gun-carriage

and a big copper boiler so that it was driven by its own power. There was too much danger of the passengers being scalded to death to make the machine at all popular, and being convicted of an aggravated assault upon a stone wall, it went with other crude experiments

> "Into a limbo large and broad, since called
> The Paradise of fools."

Watt patented a road engine in 1784, and about the same time, Murdoch, his assistant, completed and made a trial of, a model locomotive driven by a "grasshopper engine." This is said to have run 6 to 8 miles an hour. The earliest patent for road engines in America was that secured by Oliver Evans, who obtained, in 1786, from the Maryland Legislature, a monopoly for his system of applying steam to the propelling of wagons on land. In 1804, he completed a flat-bottomed boat for dredging the Philadelphia docks, and, mounting it on wheels, drove it by its own steam engine to the river bank. Launching the craft, he propelled it down the river, using the engine to drive the paddle-wheels. Thus Evans' "Oruktor Amphibolis," as he named his machine, was the first automobile wagon and the first steam paddle-wheel boat in America. A reproduction of the "Oruktor Amphibolis," and of the Cugnot wagon also, may be seen at the Field Columbian Museum in Chicago.

The illustrations of the various automobile vehicles which will be thrown upon the screen have been sufficiently well described in various previous publications as to be familiar to readers who are interested in the subject, and require no further comment from me.

Mr. Morris and myself first took up the question in June, 1894. At that time little or nothing had been done in this country or abroad, which we could use as a criterion for our experimental work; we were, therefore, compelled to attack the subject in all its bearings from an entirely novel standpoint.

In designing the first vehicle, the primary object to attain was a vehicle which should be able to propel itself through any of the streets of our city, irrespective of their suitability

for motor-vehicle traction; because if this object had not been attained, the first criticism would have been that such a vehicle might be useful under ideal conditions of road surface, but for practical every-day life it would not be successful. We, therefore, sacrificed the most important features considered by carriage makers as absolutely essential in order to made a motor vehicle successful, such as weight, design, size and distribution of machinery. As a consequence of this sacrifice, our first vehicle, while not presenting an attractive appearance to a carriage builder's eye, has accomplished all and more than we expected of it.

We got this first vehicle in operation August 31, 1894, since which time it has been in constant use, except during the winter months, and has traveled several hundred miles without serious mishap or accident, all over the streets of Philadelphia, some of which are still in very bad condition for mechanical traction, and through parts of Fairmount Park; and, up to the present time, we have never been compelled to attach a horse to it to bring it home, for any reason whatsoever.

The total weight of the vehicle, including the battery, without passengers, is 4,250 pounds. The weight of the battery is 1,600 pounds. The maximum mileage on one charge is 50 to 100 miles, according to speed and grades. The maximum speed attained is 15 miles per hour. Number of accumulators, 60 of 100 ampère-hours capacity each. Electrical capacity of battery, 13 horse-power hours at maximum discharge rate. The motor is a nominal 3 horse-power "Electric Launch Type," built by the General Electric Company, and capable of developing, for a short time, as much as 9 horse-power. The motor weighs 300 pounds.

The motor is connected, through a pinion on the end of the motor shaft, to a secondary or countershaft, having a balance gear to enable the wheels to move independently in turning curves. This countershaft has, on the ends, pinions gearing into large gears attached to the rear wheels of the wagon. The front of the wagon rests upon a fifth wheel, of 30 inches diameter, which is attached by an iron frame

to the rear axle. The lower half and revolving part of the fifth wheel rests on the springs between it and the front axle. This fifth wheel turns on hardened steel balls, being moved by a pinion and shaft with suitable reducing gear, which is operated by means of the hand wheel on top of the shaft, thus securing ample power, as well as facility in steering.

The controller regulating the current is placed in front of the footboard and operated by shaft and crank immediately below the steering wheel.

The vehicle has a seating capacity for six, but there is ample power, if seats were provided, to carry from twelve to fifteen people. The wheels are ordinary heavy wagon wheels, without ball bearings and with iron tires.

The experimental data obtained from the operation of this vehicle proved conclusively that on good pavements we could propel a vehicle weighing, with passengers, 5,000 pounds, 10 miles an hour, with an expenditure of energy of not over 3½ horse-power or $\frac{7}{10}$ of a horse-power per 1,000 pounds. With this information and the experience gained by operating this first vehicle, we were ready to start in to construct a second vehicle to compete in the "*Times-Herald* Motocycle Contest," with results which have proved highly satisfactory, not only to ourselves, but also to the engineering world.

Our "Electrobat No. 2," which competed in the race on November 28th, and which is designed to carry four passengers, including the driver, weighs only 1,650 pounds, complete with batteries, which you will notice is a substantial decrease over the first one constructed. It presents a very handsome appearance, and, at first sight, one is not sure it is not some new style of surrey. No machinery of any kind is in signt, with the exception of the steering lever, and it is exempt, therefore, from the criticism generally passed on motor vehicles, that they look more like a piece of machinery than a pleasure carriage. The body was built by the Chas. S. Caffrey Company, of Camden, N. J., one of the most famous carriage concerns in the country. There are two "Lundell" motors, of nominal 1½ horse-power capacity each,

Morris and Salom Electrobat. No. 2.

attached to the front axle, and pinions on the armature shafts gear directly into the driving gears attached to the front wheels. The steering is accomplished by turning the hind wheels parallel with each other from a point about 3 inches inside the plane of the wheels, and connected by a rod to a vertical lever of a convenient height, to be operated from the front seat of the carriage.

Although at first sight it might be supposed that steering from the rear would be more difficult than steering from the front, and, notwithstanding the concensus of opinion among carriage men was decidedly opposed to rear steering, yet, as a matter of fact, this has not been found to be the case, as the carriage can be moved, with the slightest effort on the part of the driver, and with the greatest certainty, in any direction desired, and can be turned completely around in a circle of 20 feet in diameter.

The wheels are of wood, and of the usual construction, except that they are fitted with pneumatic tires and ball bearings. The question of the desirability of using pneumatic or cushion tires on a vehicle of this weight was considered very carefully, and here again the carriage men were decidedly in favor of the cushion tire; but, desiring to be abreast of the times in all details that could add to the efficient and successful operation of the machine, we decided to risk the use of pneumatic tires. Our experience so far, while limited in this regard, justifies us fully in having taken the risk, and we feel absolutely convinced that, with some slight modifications, the pneumatic tire is decidedly the best for motor vehicles.

The driving or front wheels in the case of this particular machine are 40 inches in diameter, and the rear, or steering wheels, 28 inches in diameter.

The batteries were furnished by The Electric Storage Battery Company, of Philadelphia, and consist of four sets of twelve cells each, having a normal capacity of 50 ampère-hours per cell. They are grouped in boxes, and so arranged that they can readily and quickly be pushed into place inside of the body of the carriage, connection being automatically made with the controller. The actual time

required to take out one set of batteries and replace them with another is less than two minutes.

The controller is a small instrument, standing in a convenient position vertically in front of the seat, and is operated by means of a small hand-wheel on top. There are three speeds ahead and one backward, which are obtained by various groupings of the batteries and motors in series and parallel. The carriage has a maximum speed of 20 miles an hour on a good road or street pavement, and the capacity of the battery is sufficient to propel it from 25 to 30 miles.

Up to the present time, we have used only two different styles or types of battery, and it is our purpose to adhere, in the future, if possible, to one single type, irrespective of the size of the vehicle or the character of work required; and we will obtain the different requirements for varied service by changing the number of cells used on the vehicle, and by various methods of grouping the same through the controller. The type that we have fixed upon is a 50-ampère-hour cell, weighing about 13 pounds complete. Twelve of these cells are grouped together in a single box or tray, with brass plates on the sides for automatic contacts. These boxes or trays of batteries represent, at the maximum rate of discharge, exactly 1 kilowatt hour, or $1\frac{1}{3}$ horse-power hours, and, as they weigh only about 160 pounds each, they can readily be handled by two men; four such boxes or trays are sufficient to propel an ordinary delivery wagon, weighing about 1,000 pounds, 25 or 30 miles.

We believe that the most practical application to which these vehicles can be put, at the present time, is for service in parks and as delivery wagons. We do not consider it practicable, at the present time, to send out such vehicles broadcast over the country before any proper arrangements have been made for their intelligent care and maintenance. We think that the proper plan for their introduction is to construct a sufficient number of vehicles of one kind to warrant the building of a charging station, where the batteries can be charged and the vehicles kept when not in use. This will enable a systematic and intelligent inspec-

tion of the various parts of the machines, such as all mechanical contrivances require, and will prevent all the troubles that would naturally arise from inexperienced persons handling and operating them.

The various parts of the machines can at first be purchased and then assembled at the station. This will permit of securing the best talent in the several lines of industry, which go to make up a complete machine. The carriage builders will build the bodies, the electrical manufacturing companies the motors, and so on through the list. A building in a suitable central locality can be purchased or leased, and the vehicles can then be operated either on a lease or rental plan, very similar to the manner in which a livery stable is at present conducted, thus assuring to the owners or lessees a complete and reliable service, such as they could not secure at first by attempting to operate the vehicles themselves. After becoming sufficiently familiar with their operation and the cost of conducting the same, the lessees will then be justified in making their own personal arrangements.

The station would be equipped with dynamos for charging the batteries, and with a sufficient amount of machinery to make all necessary repairs and renewals of motors or batteries. Of course, after fifty or one hundred such vehicles get into actual daily use, their introduction, we believe, will be as rapid, and the growth of the business as marvelous, as that of the bicycle.

While we have made no close estimates as to the cost of manufacturing in quantity, we believe that ordinary delivery wagons can be constructed for from $600 to $800, and pleasure carriages from $1,200 to $1,500; while for larger vehicles or special designs, the prices will vary as much as they do in the ordinary carriage business at the present time.

The magnitude of the business and the possibilities which it may assume in the future can best be considered by comparing the work that is now done with horses, and that which could be accomplished by motor vehicles. At the present time there are probably no less than 100,000 horses in Philadelphia. It costs to keep these horses, on an

average, including feeding, shoeing, harness and depreciation or life of the horses, not less than $1 per day, or, in round numbers, about $30,000,000 a year. The work they do could be accomplished by motor vehicles at an expense not to exceed 50 cents a day, or about $15,000,000 a year, thus making a net saving in this one city alone of $15,000,000 per annum. Such a statement as this settles forever the question of good roads or good streets, as it is not contended that motor vehicles would be eminently successful under conditions that can scarcely be tolerated with animal traction at the present time. No further argument would be necessary for the rapid and permanent improvement of all streets and roads in the country, as the enormous saving that would be effected by the introduction of motor vehicles would repay the taxpayer ten-fold in a few years. They would want not only good roads, but also perfect roads, and each city would vie with its neighbor in getting the most excellent pavements that could be laid. Ideal pavements for a city being a heavy bed of solid cement from curb to curb, and as nothing but rubber tires would be used, and as the wear and tear upon the pavements would be practically nothing, it would pay every city in the Union to effect a loan to build colossal subways capable of taking care of all the underground work, so necessary and essential in large cities, and make a permanent pavement above.

The introduction of electrically propelled vehicles will open up an entirely new and immense field for the use of storage batteries, and as The Electric Storage Battery Company, of Philadelphia, controls all the basic patents for the manufacture and use of storage batteries, the new industry about to be launched will greatly increase the volume and magnitude of its business.

Electrobat No. 3 might be said to be a study in automobile design, as may be seen when the picture is thrown upon the screen. It is merely a skeleton or framework, upon which almost any kind of wagon or carriage body can be placed. The design, which is entirely the work of Mr. Morris, is new, and differs radically from anything of this kind ever constructed.

The frame consists essentially of two tubular rings, spaced apart by tubular struts, and forming convenient attachments for the springs and front axle, leaving ample space for the motors and their attachments. At the rear of this frame and attached to the cross-struts is a truss frame, forming the support for the battery and resting on the hind axle, which, in this case, is provided with a "Crawford" universal fifth wheel. This construction admits of various modifications to suit the peculiarities of different styles of vehicles. This vehicle is steered from the rear wheels by means of a lever or other gear, as may be found most convenient. It is of tubular steel construction throughout, and the wheels are built on bicycle principles, having steel spokes and pneumatic tires and ball bearings.

The method of gearing and general operation of the machine is similar to that of the large Electrobat No. 2, above described.

This machine has a maximum speed of about 20 miles per hour, the complete weight, with batteries, being 1,180 pounds. It was built by the Crawford Wheel and Gear Company, of Hagerstown, Md.

Electrobat No. 4 was built for the purpose of demonstrating the practical application of electric traction, with storage batteries, to existing types of vehicles. The standard tubular gear of the Crawford Wheel and Gear Company, of Hagerstown, Md., was selected, and, with the slight modification in the rear axle of an additional tubular shaft on which to suspend the motors, and the addition of a steering gear, is precisely what it is now selling, and what is generally known as the Crawford Pneumatic Run-About Wagon. "These gears are made of weldless steel tubing, shaped like the ordinary side bar and axle. The axles are arched or dropped to correspond with the height of wheel used. The connections (with the exception of the fifth wheel) are brazed as if in one piece. There are no bolts, clips, nuts, etc., to loosen and rattle, and positively no joints except necessary working parts. It has ball-bearing spindles and steel-spoked wheels, with pneumatic tires with 'Crawford non-creeping device,'" being the lightest electri-

cal road machine ever built. It has a maximum speed on levels of over 15 miles per hour, and a distance capacity of from 20 to 25 miles.

	Pounds.
The gear weighs	50
Wheels	64
Body	86
Battery	350
Motors	150
Controller and plate gears	50
Sundries, about	50
Total	800

THE DISTINCTIVE POINTS OF ADVANTAGE POSSESSED BY THE ELECTRICALLY-PROPELLED VEHICLES ARE AS FOLLOWS:

(1) Absolute safety.
(2) No noise.
(3) No vibration.
(4) No heat.
(5) No odor.
(6) Simplicity of construction.
(7) Ease of handling.
(8) Perfect control.
(9) Cleanliness.
(10) Economy of power.
(11) Economy of operation.
(12) Cost.
(13) Elegance of design and freedom from mechanical appearance.

Considering these points in their order—first, as to safety. A vehicle propelled by storage batteries is absolutely free from danger to life or property. Can the same be said of a gasoline vehicle carrying from 8 to 10 gallons of gasoline? Would you be permitted to store such an amount of gasoline in a barn or stable without forfeiting your insurance; and would not the general introduction and handling of such vehicles, by inexperienced persons, result in a loss of life and destruction of property? Can a vehicle using such a fuel be considered to have general utility and adaptability?

Would it be practicable to operate delivery wagons, say of Adams Express Company or any other large corporation,

having hundreds of wagons at their barns or stations, and store sufficient gasoline, amounting to thousands of gallons, to operate them all? This is a vital point, as no system can be properly considered to have general utility which is handicapped by its own inherent dangers.

(2) As to noise. The electrical vehicle is almost noiseless. It does not begin to make the noise that even a horse makes on a dirt road, while a gasoline vehicle must, perforce, make a continuous puffing noise, due to the exhaust from the motor, and this is not only disagreeable, but to some people alarming.

(3) Vibration. Owing to the rotary action of an electric motor, no vibration of any kind is communicated to the vehicle, whereas, in a gas or gasoline engine, which is operated by the explosive force of gas or vapor in a cylinder, there is a constant jarring and vibration, due both to the explosions and to the rapid reciprocating motions of the piston and rod and its connections through a crank to the fly-wheel.

(4) Heat. As there is no fire or consumption of fuel in any way on an electrical vehicle, there is, of course, no heat developed; but in a gasoline vehicle, the constant ignition and explosion of the gasoline raises the temperature of the cylinder to such a point on a long run as to prevent lubrication of the cylinder, and to endanger the successful operation of the motor. To prevent this trouble, water circulation is necessary, and very often even this is not sufficient, and ice in quantity has to be carried in order to keep the cylinder cool enough to allow the motor to perform its normal work.

(5) Odor. Of course, there is absolutely no odor connected with an electrical vehicle, while all the gasoline motors we have seen belch forth from their exhaust pipe a continuous stream of partially unconsumed hydrocarbon in the form of a thin smoke with a highly noxious odor. Imagine thousands of such vehicles on the streets, each offering up its column of smell as a sacrifice for having displaced the superannuated horse, and consider whether such a system has general utility or adaptability!

(6) Simplicity of construction. Aside from the æsthetic considerations above enumerated, the electrical vehicle

admits of a simplicity of construction which it is impossible for a gasoline vehicle ever to attain. No engine, gas or steam, was ever built that at all approaches in simplicity an electric motor, and when such a motor is geared direct to the driving wheel by a single pinion on the armature shaft, it would seem that the very last degree of refinement in simplicity of construction had been reached in the electrical vehicles under consideration. Compare this construction with the marvelously complicated driving gear of a gasoline vehicle, with its innumerable chains, belts, pulleys, pipes, valves and stop-cocks, etc., and then put the question—Is it practicable? Is it not reasonable to suppose, with so many things to get out of order, that one or another of them will always be out of order? Does so complicated a structure possess the elements of general utility and adaptability?

(7) Ease of handling. The last point considered naturally brings us to the next feature, ease of handling. With so complicated a mechanism as that described above in the case of gasoline vehicles, it would be absolutely essential to have a skilful engineer and machinist to operate them. While it might be possible to instruct an ordinary man or woman how to steer the machine and to put on or take off the power, yet, for its successful operation, this would not be sufficient, as it would be imperatively necessary for them to be familiar with any or all the troubles that would naturally arise from imperfect mixture of the air and gas, or the proper amount of gasoline necessary to feed into the mixture, and, in fact, to possess a working knowledge of the various parts of an engine and how to keep them lubricated and in proper working condition; whereas, on an electrical vehicle, we can take a boy twelve or fourteen years of age, or a young lady accustomed to driving a horse, and, with ten minutes' practice, they can operate the vehicle perfectly. Of course, we do not mean to claim that no technical knowledge is required in connection with electrical vehicles; on the contrary, the proper care of batteries requires skilful and intelligent workmen, but such work is independent of the operation of the vehicle, and is, in fact,

done when the vehicle is not in use. Once place the charged batteries on the vehicle, and you are ready to start without any complicated conditions being complied with.

(8) Perfect control. This point has to do with the steering apparatus and the method for regulating the speed of the vehicle. While a safe and certain method of steering is essential in a motor-vehicle, there are many ways of accomplishing the same result. We have employed three different methods, all of which work satisfactorily. The regulator for controlling the speed is worked with the left hand, and the current can be turned on or off instantly, and the vehicle brought to a standstill by a brake worked by the foot, and then, if so desired, made to go backwards. The steering is accomplished by the right hand, and can be done with the nicest degree of accuracy in any direction.

(9) Cleanliness. This point properly belongs to the æsthetic condition first mentioned, but the electrical vehicles enjoy a marked advantage in this respect over their gasoline competitors.

(10) Economy of power. It is proper for us to state that we do not believe any of our competitors can show such small losses of power for internal work as we do in our machines. As a result of this, we are able to do the same work with a smaller expenditure of energy. For example, during the tests of our vehicles which were made in Chicago, we developed a speed of over 20 miles per hour with an input to the motors of less than 3 horse-power.

(11) Economy of operation. As to this point, the cost of operating a motor-vehicle by either electricity or gasoline is so small as to be almost negligible, or, in our case, ¼ cent per mile.

(12) Cost. In the matter of cost, we feel that we can decidedly underbid the gasoline vehicles, on account of the much simpler form of our construction. For example, the vehicle under test can be sold at a handsome profit for from $1,200 to $1,500.

(13) Elegance of design. This last point, while the least important of all those discussed, should be given its due proportion of merit. This is a matter that must necessarily

be left to the carriage builder; but, owing to the extreme simplicity of the mechanical equipment of an electrical vehicle, compared with a gasoline motor-vehicle, it would seem as though it would be a much easier problem for the carriage builders to solve.

From a table published by the Equitable Electric Railway Construction Company, as to the horse-power necessary to propel 1,000 pounds, at various speeds and up various grades at same speed, I find that, on a level rail, at 12 miles per hour, it requires 0·320 horse-power per 1,000 pounds. While we have had but little opportunity to test our new machines, it is interesting to compare the few readings which we have already obtained with this table. These readings have all been obtained from Electrobat No. 2. Assuming the weight of vehicle and two passengers to be about 2,000 pounds (1,650 pounds of vehicle and 350 pounds passengers), the horse-power required for speeds Nos. 1, 2 and 3, on levels, is as follows:

Speed.	*Ambères.*	*Volts.*	*Watts.*	*Miles per Hour.*	*Horse-power.*	*Horse-power on Rails.*
1	6	96	576	5	·77	0·266
2	15	96	1,440	12	1·90	0·64
3	30	90	2,700	20	3·63	1·066

Trautwine gives 91 pounds as the tractive effort required to move a ton 10 miles per hour, on levels; this is equal to 2·4 horse-power. As we have been able to move a ton 12 miles per hour with 1·9 horse-power, we must attribute the increased efficiency obtained to pneumatic tires and ball bearings.

DISCUSSION.

DR. ROB'T GRIMSHAW.—What is the weight on drivers?

MR. SALOM.—About 1,000 pounds.

MR. JOHN H. COOPER.—The most important feature, for which no adequate provision seems to have been made on the machine exhibited here to-night, is the importance of controlling its speed while descending grades and for sudden stoppages, to avoid accidents by collision. In a hilly country, safety going down hill is as important as ability to go up the same. Of course, on good roadways, like the

avenues in Chicago, the ordinary brake may answer the purpose of a check or stoppage, provided the wear and tear on the tires does not too rapidly destroy them. If iron tires, as now used, be adopted for certain kinds of service, the brake, as usually made and applied, may become the cheapest and most readily applied method of arresting the motion of these vehicles, and that, upon all roadways, whether level or undulating.

I would suggest for the consideration of Mr. Salom, as a feature which I believe to be worthy of experiment, a modification of the *motor*, such that it may become a *dynamo*, and thus return to the batteries (while the vehicle is propelled by gravity in descending grades) a part of the motive force which was expended in ascending. As the change of electric current could be made instantly and easily, and perhaps with less first cost of mechanism to accomplish the desired result, there would seem to be no reason why such a method of controlling speed should not be adopted. The chief advantage of this method would, perhaps, be the partial restoration of electromotive force to the batteries, by which, in many journeys, the machines would be enabled to get back home again, without extraneous assistance.

In general, with such devices, the amount of motive force necessary for any round trip will be measured as for the same on a level roadway; the extra expenditure of force to ascend would be nearly restored by the returned force developed by the descent.

With such devices you would obtain as full control of stopping motions as you now have of guiding, both of which are absolutely necessary in crowded thoroughfares, as well as on hilly roads.

MR. SALOM.—The use of the motor as a dynamo to develop current for charging the batteries in descending grades is quite an old one, but the additional advantage gained would not compensate for the complications involved in accomplishing such a result.

DR. GRIMSHAW.—What about the brakes? Experience shows that on long grades the ordinary brake applied to a bicycle tire will ruin it very shortly. On some of the

long Virginia hills, if a rider loses his pedals, and must control by the brake, the tire is often ruined in one "coast."

MR. SALOM.—The question of braking is one that will not have to be considered very seriously until motor vehicles become more largely introduced for country service. The ordinary brake device, with which the present vehicle is equipped, is amply sufficient for any grades that may be encountered in a city like Philadelphia, and, indeed, is quite sufficient for very steep grades, if the speed of the vehicle is not allowed to become too great before the brake is applied. The ability to reverse the machine, moreover, is another source of braking, which could be used in any emergency to avoid accidents. For very steep grades, it would, perhaps, be better to have a band brake applied on the armature shaft.

DR. GRIMSHAW.—How quickly can the machine be swerved from a straight course? In close quarters an intelligent horse will swerve and avert a collision before his driver will receive and weigh the impression and pull the proper rein, and the horse receive and act on the impression. It is often promptness, rather than accuracy of guidance, that is essential.

MR. SALOM.—In regard to steering, or swerving from a straight course quickly, when going at a high rate of speed, I would say that the machine responds to the motion of the steering lever instantly, and it would seem that the ability to avert collision would be largely a matter of the personal equation of the driver, some minds acting very much more quickly than others.

MR. WM. L. DUBOIS.—I would like to ask Mr. Salom whether he has made any estimate as to what it would cost a user of a vehicle to operate it after all arrangements for storage house, etc., as proposed, shall have been completed.

MR. SALOM.—The cost of operating such a vehicle as we have exhibited here this evening, when proper arrange ments for its care and maintenance had been made, would not exceed 50 cents a day for 25 miles.

DR. GRIMSHAW.—Isn't $1 a day a liberal estimate

for keep of horse? At expensive stables in New York City, the charge for boarding a horse and caring for harness and wagon is only $30 a month.

MR. SALOM.—In regard to my estimates for the expenses of animal traction, I would say that I arrived at the figure of $1 per day per horse, after consulting with a great number of persons who use horses to a greater or less extent; and while, of course, $1 would be a very liberal estimate where a large number of horses were employed, yet it so frequently exceeds this amount in the case of private individuals, who have only a few horses, that I think the average would be above, rather than below, this amount.

MR. DUBOIS.—In the case of an electric carriage, if the owner of it should choose to lie off for a month, it would then be costing him nothing, while the expense of keeping a horse would continue.

MR. SALOM.—What Mr. Dubois says is quite correct, and the total cost of operating would be much less than I have estimated, where the vehicle is only occasionally operated, or where the service is irregular in its application. We had a good illustration of this last summer, when, owing to the heat, our first experimental wagon was not taken out of the station for nearly three months, the batteries having been charged immediately after the previous trip had been made, and, although nothing had been done to the vehicle or the batteries for that length of time, we were enabled to back the machine out of the station and make a run of 15 miles, at the rate of 10 miles an hour, without any additional charge being put into the batteries, or without the necessity of doing anything to the machine.

MR. C. J. REED.—What is the capacity of the battery, when charged, in horse-power hours?

MR. SALOM.—About 5 horse-power hours, at maximum rate of discharge.

MR. SPENCER FULLERTON.—What difficulties have you met from the prejudices of the community, or from the prejudices of the authorities? Has the latter prejudice led to the enactment of absurd laws against automobile vehicles, restraining their natural and proper development, as

has been the case in England? For example, liability for damage caused to or by frightened horses, would be one point; others are: increased rates over horse-drawn vehicles on toll roads; responsibility for injury to roads and bridges; unnecessarily wide tires, enforced in the case of the automobile, etc.

MR. SALOM.—We have met with no difficulties from the prejudices of the community, nor have we found that our vehicles would frighten horses. It is very rare that a horse pays any more attention to our vehicles than he would to an ordinary carriage. Of course, some horses occasionally show evidence of being a little frightened, but no runaways have ever been caused, nor has any accident of any nature whatever happened, from the operation of these vehicles in the streets or park. Up to this time no restrictions of any nature whatsoever have been put in force against the motor vehicle.

ELECTRICAL SECTION.

Stated Meeting, Tuesday, January 28, 1896.

MR. CARL HERING, President, in the chair.

THE EVOLUTION OF THE STORAGE BATTERY.

BY MAURICE BARNETT.

In 1801, Gauterot, while decomposing salt water electrolytically, noticed that on breaking the circuit he could obtain a current of short duration from the electrodes. A few years later, Ritter constructed a pile consisting of disks of copper, separated by pads moistened with saline solution. After passing a strong electric current through the pile he was able to obtain a current of considerable intensity from the pile itself.

This pile of Ritter's, while not a storage battery in the sense in which that term is now used, was, in principle, related to the modern apparatus employed for the so-called storage of electric energy. It is interesting to us as being a piece of apparatus, the theory of which would, at a later

date, have served as the basis for a generalisation which would have led to the inception and development of the storage battery. But the time was not ripe for this. To have been anything else than a scientific curiosity, the means must have been at hand for charging storage batteries cheaply. The cheapest source of charging current then known was that obtainable from primary batteries, which, on the ground of cost, prohibited the use of secondary cells. But there was another circumstance that retarded the advent of the storage battery—a circumstance founded on a misconception, which, at the beginning of the century, led investigators astray and caused them, in their desire to improve the primary, to ignore the secondary battery altogether. To appreciate this, consider the following experiment:

If we place two platinum electrodes in dilute sulphuric acid, and connect these with some source of direct current of sufficiently high E.M.F. to decompose the solution, the disengagement of gas at the negative and positive poles will at once be noted. If now the circuit be broken, and the wires leading from the electrodes be connected with a galvanometer, the needle of the galvanometer will be deflected—showing that an electric current is passing.

To-day we account for the reverse current produced in such an electrolytic cell, by saying that, during the decomposition of the solution, hydrogen and oxygen are dissociated. As soon as dissociated, they tend to recombine, and, in recombining, cause a counter E.M.F. equal to that required to effect the dissociation. It is the manifestation of this E.M.F. which causes the passage of the reverse current. Three-quarters of a century ago this was not fully understood. In the case of the Ritter pile, it was assumed that, during electrolysis, the salt was decomposed into acid and base, and that these, on recombining, produced a current. In the case of the electrolysis of pure water, or dilute sulphuric acid, with platinum electrodes, there was neither acid nor base to recombine, nor oxidation at the electrodes, to produce an electric tension; hence, investigators, looking about for causes, ascribed the action to physical, rather

than to chemical agencies. In this particular case, the electrodes were said to be "polarised," and the term "polarisation" was adopted to define the phenomenon itself.

If the early investigators of the galvanic battery had had the acumen of Gaston Planté, storage batteries would have been developed at an earlier date. Planté, it will be remembered, studied polarisation phenomena in order to utilise them. The other investigators studied to eliminate them.

Towards the end of the first half of this century, it was demonstrated that non-oxidisable electrodes, as platinum, which had been placed in oxygen and hydrogen gas respectively, would, when immersed in dilute sulphuric acid, give a current just the same as if they had been used in the electrolysis of the acid itself. This was the principle of the Grove gas battery, described in 1842 by Sir W. Grove. It is the earliest form of reversible battery that was recognised as such, and is thus of considerable historical interest. It was not possessed of qualities that would make it valuable as a storage battery, although, in principle, it embodies some features which would be meritorious in any storage battery. There are, however, practical reasons why the battery is not adapted to the needs of modern engineering.

In 1859, Gaston Planté began the researches which were to secure to the world an eminently practical invention; and for the first time, the phenomena of polarisation were made the subject of an inquiry looking to their utilisation.

Planté's investigation had in view the discovery of the behavior of different metals in an electrolytic cell. To this end, he electrolysed dilute sulphuric acid with rods of the various metals used successively as electrodes. Two to three Bunsen elements furnished the requisite E.M.F. to decompose the solution. After passing a current for some time, he disconnected the primary battery and studied the reverse current obtained from the electrodes. Of the metals used, some exhibited very slight electric capacity, *i. e.*, they furnished only a very transitory current; others exhibited considerable capacity. Of all the metals tested, he found that lead gave the greatest promise, not only on account of

its capacity, but also because of the intensity of the discharge.

In a primary battery, chemical action is concerned in doing both useful and useless work, the relative amounts of which will depend, among other things, on the nature of the electrodes. This useless work is a result of local action, by which a large amount of metal is acted upon without the production of external current. It is not too much to say that over nine-tenths[1] of the useful energy of a battery may be dissipated under some conditions by this local action, even on closed circuit, without the production of anything but heat and myriads of little currents that will play over the surface of the electrodes without entering the outer circuit.

One of the worst features of local action is that it is greatest on open circuit. With storage batteries, which may be left for weeks at a time on open circuit, it is easily seen how energy, once stored up, might be dissipated without any useful result. Here, then, it becomes absolutely essential that the electrodes should be of such a nature as to prevent, as far as possible, all action except that identified with the production of external current.

It is very plain that metals forming soluble salts are most likely to show the greatest losses in this direction, because, as fast as they dissolve, new surfaces are exposed, which permit further useless corrosion. One of two things is therefore necessary: either we must have insoluble electrodes, or the electrodes, during discharge, must form salts insoluble in the electrolyte.

As we survey the various metals that might be utilised in storage batteries, one after another will have to be discarded. Zinc, iron, and even copper, which, on account of the energy they develop during chemical action, would be even more efficient than lead, weight for weight, are objectionable on the ground of the solubility of their salts. Lead, on the other hand, furnishes salts which are practically insoluble in the electrolyte. The influence which this

[1] See *Proc. Roy. Soc.*, xxxvi, 1884.

insolubility exerts in diminishing local action is apparent on momentary consideration. The peroxide and the metallic lead of the positive and negative plates, respectively, are both converted into sulphate during discharge. The same reaction takes place as a result of local action. Now, as this sulphate forms, it gradually encloses the remaining active material, and protects it from further oxidation.

Again, the fundamental principle of the storage battery is the possibility of reversing the physical and chemical changes which take place during each discharge. With soluble electrodes, the difficulty that lies in the way of the redeposition of the metal in an efficient form seems almost insuperable. Up to the present day, effort after effort has been made to accomplish this, but without anything like a satisfactory result. The consequence is that recourse has been had to electrodes which are either insoluble, or which, like lead, form salts insoluble in the electrolyte.

At the present time, lead is the only metal used to any extent in the manufacture of storage batteries. Zinc and copper have been used with lead in what are known as the Reynier and the Sultan cells, while zinc has been used with copper in the Thomson-Houston and the Waddell-Entz cells. This departure from the lead type of battery has not been attended with success. Lead seems to be the only metal of which it can be said that it is easy to reproduce *both* the physical and chemical changes which take place in the electrodes during discharge. And not only that, but this reversal may be repeated and repeated an indefinite number of times, year after year, without the cell showing signs of excessive deterioration. This is what has made the use of lead imperative, up to the present time, and has made the manufacture of the lead storage battery successful where other types have been failures.

This merit of lead, in being susceptible to regeneration, grows out of the insolubility of its sulphate, already spoken of as being an important factor in preventing loss of energy due to local action. Two other properties of lead also adapt it for use in the construction of storage batteries. The first is that the lead peroxide used in the positive plates has

excellent conducting qualities, and that the couple formed of spongy lead and lead peroxide furnishes, in an electrolyte of dilute sulphuric acid, a high E.M.F.

Having thus reviewed, rather hastily, the reasons why lead is preferable to other metals in the construction of accumulator plates, we can understand why Planté, pursuing his investigations in 1859, with a view of utilising polarisation effects, should have concluded that lead seemed best adapted to yield these effects in the highest degree, and should have selected this metal in the construction of his accumulator.

From the illustrations in text-books on natural philosophy —and especially in the older treatises—everyone has been made familiar with Planté's spiral accumulator, which consisted of two plates, placed concentric with each other, in dilute sulphuric acid; one plate being lead, the surface of which was peroxidised; the other, metallic lead. These constituted an electric couple, which gave an E.M.F. of approximately 2 volts.

Having constructed his accumulator, Planté set about to determine the best method of "forming" the plates, that they might yield effects extending over a considerable interval of time. The procedure he adopted was to pass a current through the accumulator, first in one direction, then in the other, and so on, with intervals of rest in between. The effect at first was merely superficial; but after reversing the current and repeating the process a sufficient number of times, the metal was affected to a considerable depth, and, on the completion of the action, one electrode would be covered with a thick layer of spongy lead, and the other with a thick layer of peroxide. In such a form the electrodes were capable of furnishing currents of great density for a length of time depending on the extent to which the plates had been affected by the electrolytic processes to which they had been subjected.

It is very evident that "forming" plates by the process just described not only consumed much time, but was also attended with considerable expense, owing to the fact that the only current available for this work was that

obtainable from primary batteries. These circumstances operated to prevent anything more than a theoretical interest being taken in the subject.

Between 1859 (when Planté began his experiments) and 1880, when Faure invented the pasted battery, great changes had taken place in the condition of the electrical arts and manufactures. The dynamo electric machine had, by this time, been perfected, and offered the means for the cheap production of currents of great density and high E.M.F. This circumstance put the storage battery on a different footing, and held out promise of the utility it would enjoy with the further development of the electrical arts.

Faure's invention was the outcome of efforts to reduce the cost and minimise the time factor in the Planté process of "forming." To this end, he made pastes of minium (red lead) and litharge—oxidised compounds of lead, represented, respectively, by the chemical formulæ, Pb_3O_4 and PbO—which he applied to the surface of the positive and negative plates. When these were subjected to the "forming" process, the red lead was oxidised to peroxide and the litharge reduced to spongy lead, with a material saving in time and costs over the Planté process of producing corresponding changes in solid lead plates.

Scarcely had the Faure plate been brought out than accumulators were put to a variety of industrial uses, amongst which may be mentioned their application to carry the day load in lighting stations and to prevent the necessity for running dynamos at night in private residences. The practicability of charging accumulators, when this could be conveniently done, and discharging them at pleasure, either alone or in conjunction with dynamos, was a very inviting possibility, which was taken advantage of from the very outset. It was also frequently suggested to employ some central stations exclusively for charging accumulators, to be distributed afterwards to furnish light and power. Even for traction purposes, where accumulators are subjected to the severest demands, their use was proposed as far back as 1880. In that year, experiments

were begun, looking to their utilisation in this field, and in 1883, a car went into service at Kew Bridge, London. This car was equipped with a Siemens dynamo, set to run as a motor, and about 4,000 pounds of batteries.

As might have been foreseen, the storage battery was put upon the market in a crude and undeveloped form before it had been sufficiently studied by the chemist and physicist and improved by the manufacturer; and, in addition to this, it was applied to a variety of purposes, for which, in its early form, it was notoriously unfit. The result was that, in nearly all of its various applications, it proved a failure—a circumstance that has had a great deal to do with creating a prejudice against storage batteries, which to this day has been ineradicable, although secondary cells, as now constructed, are vastly superior to the crude forms of 1880, and are in successful operation in hundreds of interesting applications, where their use is, in every case, attended with satisfaction. To-day, the extension of the use of the storage battery is looked on with growing favor.

Modern storage batteries date from the invention of Faure, and 1880 marks the year when their commercial applicability became assured. Up to within a few years the pasted lead battery was the only form of storage battery in use to any extent. Recently the Planté type of battery has again come into favor, together with an improved form of battery known as the chloride accumulator. These are all lead batteries, and differ from one another only in the method of their construction and formation.

In the following paragraphs these three types of lead batteries will be considered in the order named.

Planté batteries are made in diverse forms. In the first place, there are the solid plates with striated surfaces. Then there are the various forms of laminated plates, where the greater part of the body of the plate consists of ribbons of lead. Then, again, there are other forms where porosity is given to the lead by kneading it hot with some porous material, which may afterwards be dissolved out. These various forms are all subject to innumerable modifications.

The objects aimed at by increasing the surface of the lead per pound of material, are: first, to facilitate the forming process (it is easy to see that the more surface there is, the more lead will be exposed to the electrolyte, and the more quickly will electrolytic action accomplish the requisite formation); second, to increase the capacity of the plates, *i. e.*, the ampère-hour output per pound of the elements; third, to permit changes of volume to take place in the active material without prejudice to the life and efficiency of the cells.

The method of forming the plates, *i. e.*, bringing the negative to the spongy lead, and the positive to the peroxide state, varies with the place where the process is carried on. At some works these changes are brought about by the old Planté process. This method, proving tedious, has been superseded by an electro-chemical treatment, by which the plates are brought into the desired state much more quickly than by electrolytic action pure and simple.

The characteristics of the Planté type of battery are: capability of giving heavy discharges without sustaining injury, minimum local action and general freedom from the irregularities due to local action.

Up to within a few years, the pasted battery monopolised the attention of inventors and supplied the needs of those using secondary cells. It superseded the Planté battery at the start, because it offered the means whereby plates could be quickly formed, which would possess large capacity for a given weight of elements, and be capable of momentary heavy discharges without being much injured.

The Faure, or pasted battery, is made by applying a paste of lead oxide (minium, Pb_3O_4, for the positives, and litharge, PbO, for the negatives) to perforated or solid "grids." Now, if two such plates be used as electrodes in a bath of dilute sulphuric acid, and the bath be decomposed, the liberation of hydrogen at the negative pole will reduce the litharge to spongy lead, while the liberation of oxygen at the other pole will oxidise the minium to lead peroxide.

So great an improvement was the Faure battery supposed to be over that of Planté, that between 1880 and 1890 it was

thought, generally, that no commercial storage battery could be made that was not of the pasted type. It is only necessary to examine the early forms of Faure batteries to see that they fall far short of being an even approximately perfect medium for the storage of energy. When such cells go into service, local action is set up between the active material and the grid, because of the imperfect contact between them. This, among other things, leads to loss of the charge of the battery. This contact is rendered still more imperfect with time, by reason of the sulphate of lead, which forms and insulates the active material from its support. Moreover, in the active material, which is an ordinary mechanical mixture, expansion takes place in every direction; and as no allowance can be made for taking up this expansion, the result is that the cohesion of the particles—already weak—is weakened still more by the strains occurring within the mass itself. Under the influence of poor contact with the grid, and lack of cohesion of its particles, the active material has a tendency to fall away from its support, short-circuiting adjoining plates and producing irregularities which soon bring the usefulness of the cells to an end.

One form of modern pasted plate requires particular mention. It is known as the Tudor positive. This plate is heavy and thick, with surface channelled so that the active material will find better support. Red lead as a paste is applied to both sides of the plate, which is afterwards formed by electrolytic action. This type of battery is widely used, and has qualities which specially adapt it for central station work. Thus, it is capable of yielding its entire charge in one or two hours. Now, as the maximum demand in a central station lasts for an hour and a half, or at most for four hours daily, it is found to be considerably cheaper to install storage batteries rather than direct generating machinery, to take care of this extra load. For this special work Tudor batteries are very largely used. As illustrating the great value they possess as an auxiliary of dynamo machines, it may be stated that in Prussia and Austria they are found in 80 per cent. of the central stations, in numerous railway plants, and in thousands of isolated lighting plants.

The "chloride" battery takes its name from the fact that the active material of the plates is made from lead chloride, rather than from metallic lead, as in the Planté, or lead oxide, as in the pasted batteries. Without going too much into construction details, it will suffice to say that lead chloride is cast into small pastilles with beveled edges. These, spaced in moulds, have antimonial lead cast around them under pressure. The resulting plates, alternating with sheets of zinc, with which they are in dead-short-circuit, are then placed in a solution of chloride of zinc, and allowed to remain until the zinc chloride has been dissolved out and the lead brought to a metallic state. Close examination of these plates reveals the fact that the active material is porous and of fine crystalline structure. Positives are formed from these plates by electrolytic action.

The claims made for this type of battery are: (1) that good contact between the active material and the support is assured by the beveled edges of the original chloride tablets and the lead forced around them under pressure; (2) that the crystalline formation of the active material permits changes of volume in these masses to take place, without producing any strains within the masses themselves; (3) that the cohesion of a crystalline mass is always greater than that of a mechanical mixture; (4) that the porous condition of the active material secures large capacity per pound of elements; (5) that the porous condition of the active material facilitates the "forming" process. These claims all seem to be substantiated by the performance of "chloride" cells, which show a high efficiency in practice, very small deterioration (and therefore small cost for maintenance), capability of holding charge over considerable intervals of time, and freedom from short-circuiting, buckling, sulphating, or any of the troubles to which the old lead batteries were subject. They are thus seen to possess none of the defects of pasted batteries, while they embody all the merits of the Planté cells without their faults of structural weakness and tedious formation. In one sense they are Planté cells, but differ from this type in that the lead for the active material is prepared separate from the rest of the

plate. "Chloride" negatives are said to be the best negative plates produced up to the present time, and are frequently used with positives of other types in storage battery installations.

DISCUSSION.

MR. C. J. REED.—There are some questions raised in this very interesting and instructive paper which seem to me of great importance, and on which I am unable to agree with the author.

The first question to which I refer is that of the process of reduction of lead from lead sulphate in charging the accumulator. This reduction is stated by the author—and is generally stated by others—to be effected by the action of nascent hydrogen. In other words, it is held that the electric current first decomposes the solution, liberating hydrogen and oxygen; that the hydrogen reacts on the lead sulphate of the negative plate, producing metallic lead and sulphuric acid, while the oxygen at the positive plate acts upon the lead sulphate and water, producing lead peroxide and sulphuric acid.

It seems to me that no evidence has ever been adduced to substantiate the theory of this double reaction, and that we have every reason to believe that the charging of the accumulator results directly in the electrolysis of lead sulphate on both plates. If oxygen and hydrogen are produced as a first step by the current, we have no way of knowing it, since the gases are not evolved. The only gas evolved is that which escapes, except the small amount that becomes occluded in the porous mass. Neither the occluded portion, nor that which escapes, can perform any further chemical action. The only portion that could perform any reduction is that portion which is not evolved at all, and of the liberation of which we can have no knowledge.

The supposition that the electric current would decompose the solution more easily than the lead sulphate is entirely gratuitous. There is every reason to believe, however, that it would decompose the lead sulphate more easily than the solution.

The formation heat of PbO is 55,350 calories, correspond-

ing to an electromotive force of 1·19 volts; that of H_2O is not less than 68,360, corresponding to 1·47 volts. The formation heat of H_2SO_4 (assuming $H_2,O=68,360$ and $SO^3,H_2O=21.320$) is 89,680, and that of dilute sulphuric acid 107,530 calories, corresponding respectively to 1·93 and 2·22 volts; while that of $PbSO_4$ is only 75,552 calories, corresponding to 1·63 volts. It is known, also, that H_2O is not an electrolyte and could not be decomposed.

It is evident, therefore, that, whether we consider the reaction to be a decomposition of the oxide or the sulphate, it will require a greater electromotive force to liberate hydrogen than lead. There is no more necessity or reason in supposing the lead sulphate requires nascent hydrogen for its reduction than there is for supposing that copper is reduced from copper sulphate in electro-plating by the action of nascent hydrogen.

Another sufficient proof that there is no primary decomposition of H_2O or H_2SO_4, is, that if the hydrogen were more easily reduced than lead by electrolysis, the hydrogen so reduced would not be able to reduce the lead. It is merely a question of whether lead or hydrogen has the greater heat of combination per electro-chemical equivalent. The figures given above, and which are generally accepted as correct, ought to settle this question.

This explains satisfactorily why a discharged accumulator does not gas at the beginning of the charge, particularly with a small current. There is in the discharged accumulator an excess of lead sulphate accessible to the action of the current, and the current is all employed in doing useful work, decomposing lead sulphate on both plates, the reaction being as follows:

$$\underset{\text{Pos. Plate.}}{PbSO_4} + 2H_2O + \underset{\text{Neg. Plate.}}{PbSO_4} = Pb + PbO_2 + 2H_2SO_4$$

As the charging proceeds, the lead sulphate is used up, and the current, which must continue to perform an equivalent amount of electrolytic work, necessarily decomposes some of the solution, evolving free oxygen and hydrogen. This also explains why a higher electromotive force is required to send a given current through the cell at the end of the

charge than at the beginning; and it explains also why a large charging current in a cell of small active surface produces, even at the beginning of the charge, a large amount of electrolytic gases.

Furthermore, the only products of discharge that have ever been found are, as stated by Gladstone and Tribe, H_2SO_4 and $PbSO_4$, the latter mixed in varying proportions with PbO_2 on the one plate and with Pb on the other. The only lead products of the charging process that have ever been found are lead and lead peroxide. Under some circumstances there is formed in the solution some H_2O_2, O_3, and $H_2S_2O_8$, but no lead persulphate, or any other compound of lead except the peroxide. If any lead persulphate were formed incidentally in charging, it would immediately be dissolved in the solution, and could no longer be considered a part of the active material of the electrode. Its gradual spontaneous decomposition would cause a white precipitate of lead sulphate in the bottom of the cell. But to consider such a product as the normal result of charging an accumulator, or as an intermediate step in the formation of lead peroxide, is out of the question. If such were the case, the active material of the positive plate would all go into solution the first time it was charged. The only lead persulphate known to exist is so highly soluble that it can be brought into the solid state only by evaporating its solution in vacuo.

The second question raised in this paper, on which I am unable to agree with the author, is the statement that an insoluble active material is necessary or desirable in an accumulator in order to prevent local action. It seems to me that any insoluble coating that prevents local action must do so by preventing chemical action. It would, therefore, prevent the normal action of charge and discharge in the same degree that it prevents local action. This is one of the things that is certainly not desirable in an accumulator.

Local action is not due, I believe, to the contact of the active material and solution, but to the existence of local galvanic couples. If these can be removed without insulating the solid from the liquid portion of the active mate-

rial, that would seem to me a better method. This local action is illustrated in the primary zinc battery. Zinc, even chemically pure, immersed in dilute sulphuric acid, will be dissolved by the galvanic action of local couples due to differences in density of adjoining parts, or the junction of crystalline and amorphous particles. By thoroughly amalgamating the zinc, its molecules are brought into solution in the mercury, and the surface thereby rendered homogeneous. Local action is in this manner entirely prevented.

I believe, therefore, that an accumulator having no insoluble coating to incrust and insulate the active material would be more nearly the ideal than one in which the reactions are encumbered by a solid insulating product.

The author of the paper states, very truly, that the difficulties of the lead-zinc accumulator arising from the spontaneous discharge by local action on the zinc plate, have, up to the present time, proved insuperable. It cannot be denied, however, that, if its difficulties could be removed, it possesses certain advantages, as stated by Mr. Barnett, over the lead type. It gives a considerably higher electromotive force, and can be made much lighter for a given capacity.

As to the difficulty caused by local action, this seems to me not entirely insurmountable. I have experimented to some extent on this problem, and have found that, by proper management, it can easily be controlled. I find no difficulty in producing an accumulator of this type which will, with very large surfaces exposed, retain 50 per cent. of its charge for about two months. As a matter of fact, the discharge of the peroxide plate seemed to be more rapid than that of the zinc plate. When we consider that for many purposes it is desired to retain the charge of an accumulator only a few hours, the loss is reduced to a small fraction of 1 per cent., which is practically negligible. I believe, therefore, that there is a large field of usefulness for this type of cell.

MR. BARNETT.—In denying the reduction of lead sulphate by means of hydrogen, Mr. Reed adopts a view of the changes taking place at the negative electrode, which he will find difficult to prove—namely, that the electrolytic decomposition of $PbSO_4$ is accomplished without the agency

of hydrogen, and that the electrolyte is not decomposed until the above-mentioned electrolysis of $PbSO_4$ has been effected. In support of his view he cites thermo-chemical data to prove that, inasmuch as the heat of formation of $PbSO_4$ is less than that of H_2SO_4, the former compound will be decomposed more easily than the latter, and that this reduction will take place before any gas is evolved, as a result of the electrolysis of the solution.

If Mr. Reed's figures were correct, his contention on this point might be justifiable; but, whereas he gives 75,552 c. g. calories as the heat of formation of $PbSO_4$, I find that the value of this quantity, taken from the "Thermo-Chemical Memoirs" of Thomsen, is 145,130 c. g. calories—a value nearly twice as large as that given by Mr. Reed. Obviously, $PbSO_4$ will require for its decomposition a higher E.M.F. than H_2SO_4 would require to resolve it into its molecular constituents, which would go far to prove that the solution *is* electrolysed before the $PbSO_4$ is reduced.

But, continues Mr. Reed, even if the hydrogen were more easily reduced than lead by electrolysis, the hydrogen so reduced would not be able to reduce the lead, for the energy of formation of $PbSO_4$ being greater than that of H_2SO_4, hydrogen could not possibly reduce lead out of the former compound. But it must not be forgotten that, in addition to the affinity of (H_2) for (SO_4), there is the E.M.F. of the cell acting in conjunction with the affinity of this hydrogen molecule. And just as (SO_4) can unite with H_2SO_4 to form $H_2(SO_4)_2$ (persulphuric acid) under the proper E.M.F. and density of current, although this compound *absorbs* heat in its formation, so we can understand that (H_2) can unite with the (SO_4) of the lead sulphate, even if energy is absorbed in this operation.

If Mr. Reed is right in stating that the electrolytic decomposition of $PbSO_4$ at both plates precedes the decomposition of the solution, how does he account for the fact that PbO_2 is formed at the positive electrode *from the beginning of the charge*, showing that the electrolyte was decomposed from the very outset, else, whence would the oxygen have been derived wherewith to effect this peroxidation? Fur-

thermore, if hydrogen does not participate in the reduction of $PbSO_4$, and is not occluded, it should be evolved earlier in the charging process than oxygen, for the oxygen first given off is absorbed at the positive plate in forming peroxide. But in spite of this fact, oxygen is given off earlier in the charging process than is hydrogen. As oxygen cannot be liberated without the simultaneous liberation of hydrogen, what, it may be asked, becomes of the hydrogen liberated while PbO_2 is being formed in the earlier stages of charging? The answer is that it is concerned in uniting with the (SO_4) of the $PbSO_4$ at the negative plate, to reduce metallic lead and regenerate the H_2SO_4 that participated in the discharge reactions.

The electrolytic decomposition of $PbSO_4$ pure and simple is a more difficult matter than the gentleman imagines. Dr. Lodge and Lord Kelvin objected originally to the lead sulphate theory of the action of the accumulator, because of the impossibility of reducing lead sulphate, and even Gladstone and Tribe showed that it was only partially reduced after days of electrolytic action.

With regard to the possibility of lead persulphate participating in the reactions of charge, there is nothing in the nature of this compound to preclude such a reaction taking place, as the conversion of $PbSO_4$ into PbO_2 by means of the intermediate formation of lead persulphate. Even admitting the solubility of this compound, it must be remembered that it is decomposed the moment it forms. Its solution and dispersion through the electrolyte is an impossibility. Barium chloride is a soluble salt; but if we had electrodes of $BaCl_2$ in an electrolyte of dilute sulphuric acid, no one would say that $BaCl_2$ would be dissolved and dispersed through the electrolyte. It could not exist in the presence of free sulphuric acid. In the same way lead persulphate is supposed to represent an endothermic compound, formed in the course of electrolysis, but decomposed as fast as formed, with production of PbO_2 and regeneration of H_2SO_4.

In Volume 59, of the *Journal of the Chemical Society*, London, I find, in a contribution from the chemical laboratory

of the University of Edinburgh, by Hugo Marshall, the following details of an experiment:

"If PbO be rubbed up in a mortar with a saturated solution of ammonium persulphate, considerable quantities of ammonia are liberated, but in a short time the mixture darkens from formation of PbO_2, and on treating with H_2O and filtering, no soluble salt of lead is found in the solution." Now, the explanation of this reaction is that the PbO decomposes the ammonium persulphate, with formation of water, lead persulphate and ammonia, as shown by the following equation:

$$(NH_4)_2(SO_4)_2 + PbO = Pb(SO_4)_2 + H_2O + 2(NH_3)$$

This lead persulphate is acted on by the water liberated, and also that derived from the air, which results in formation of lead peroxide and sulphuric acid, as shown by the following equation:

$$Pb(SO_4)_2 + 2H_2O = PbO_2 + 2H_2SO_4$$

This explains why no soluble persulphate of lead is found in the solution, for it has been decomposed. In charging an accumulator, $Pb(SO_4)_2$ is only momentarily formed as an intermediate product, and is decomposed as soon as formed, as shown in the above equation. The solubility of the salt does not preclude the reaction taking place, as described above.

Lastly, with regard to the necessity or desirability of having insoluble active material as a preventive of local action, I admit that if it be possible to prevent local action in other ways it may preferably be done; for the use of insoluble electrodes undoubtedly reduces the efficiency of the battery materially by preventing complete chemical action. The use of soluble electrodes is objected to, not so much on account of their liability to local action, as because of the difficulty encountered in reversing, on charge, the physical and chemical changes taking place during discharge. While lead is not a good electrode, especially for negatives, where have we any example, to-day, of cells in successful operation where *soluble* electrodes are employed?

I appreciate fully the limitations of insoluble electrodes, but the fact that storage batteries of the lead type are the

only ones of which the manufacture has been technically and commercially successful, would certainly lead one to the belief that no mistake is made in pinning one's faith to this type of cell. Of the numerous modifications of the "Sutton" type of accumulator, consisting of a lead peroxide—copper couple in an electrolyte of copper sulphate; of the "Reynier" type, consisting of a lead peroxide—zinc couple in an electrolyte of zinc sulphate; of the Thomson-Houston type, which is a reverse form of the Daniel cell; and lastly, the Waddell-Entz type, consisting of porous copper oxide and metallic zinc in an electrolyte of potassium zincate —can Mr. Reed point to any of these in successful operation to-day?

When the difficulties attending the re-deposition of metals in an efficient chemical and physical form have been worked out, there will be no reason why soluble electrodes should not be employed to advantage in constructing accumulators. But to-day these difficulties have not been worked out. Local action is only one of the disadvantages attending the use of soluble electrodes. The greatest obstacle to their use is the difficulty of reversing completely, on charging the physical and chemical changes they undergo, during discharge.

MR. REED.—It will not be profitable to prolong this discussion by merely arguing established chemical laws and questions of fact. I assumed in my previous remarks that the elementary principles of chemistry were admitted, and that Mr. Barnett had given more particular attention to certain well-recognised chemical laws. It is of no interest to discuss these questions on a basis of arbitrary supposition without any regard to the facts.

The main facts and, in my opinion, the only rational theory of the reaction that takes place in charging a lead accumulator, are to be found in an article by Leibenow, in the *Zeit. f. Electrochem.*, January 5, 1895. They are in substance the same as stated in my previous remarks.

As to the statement accredited to Thomsen, that the heat of formation of $PbSO_4$ is 145,130, this may be a typographical error or some other mistake; or the statement may be based on some misunderstanding of the article

quoted. As Mr. Barnett does not give a specific reference, I cannot say which is the case. I am sure, however, that the statement is not correct.

The results obtained by Thomsen and others are stated in condensed form in Watt's Dictionary of Chemistry (old edition, Vol. VII), under the subject of heat. On page 614 the following formation heats are given:

$$Pb,O,SO_3Aq = 4 \,.\, 18{,}888 \; (= 75{,}552)$$
$$Fe,O,SO_3Aq = 5 \,.\, 18{,}772 \; (= 93{,}860)$$
$$Zn,O,SO_3Aq = 6 \,.\, 18{,}077 \; (= 108{,}462)$$
$$Mg,O,SO_3Aq = 10 \,.\, 18{,}092 \; (= 180{,}920)$$

It seems hardly necessary to deny that lead stands midway between zinc and magnesium, as it would according to Mr. Barnett's figures, or that the formation heat of its sulphate corresponds to anything like 3·1 volts. If, as held by Mr. Barnett, the $PbSO_4$ requires this high electromotive force to reduce it, any amount of nascent hydrogen could not do it. From the quotations given above, it will be seen that $ZnSO_4Aq$ requires only 2·33 and $FeSO_4Aq$ only 2·02 volts for reduction. Yet, nascent hydrogen has never been known to reduce these metals to the metallic state. This reduction can be effected only by the absorption of additional external heat, as in a furnace; in the case of iron at a heat of 300° C.; and in the case of zinc, only slowly, at the boiling point of that metal.

The theory advanced by Mr. Barnett that the electromotive force of the charging current is added to the affinity of (H_2) for (SO_4), and that the two, acting conjointly, do the work equivalent to one is certainly new. It amounts to connecting electromotive force and chemical affinity in series in an electrolytic cell. But this theory is not likely to be accepted by any except those who are willing to abandon Faraday's law of electro-chemical equivalents and the law of simple substitution in chemistry, to say nothing of the doctrine of the conservation of energy. It is certain that nascent hydrogen and electric current do not act in that way in any other reduction. In all other cases where nascent hydrogen acts in conjunction with electric current, or any other reducing agent, the result is an amount of metal

reduced which is the sum of the amounts reduced by each reagent acting separately, instead of being an entirely different reaction from that produced by either one alone. In other words, several reducing agents mixed together in the same solution always act in parallel and never in series.

If this novel theory were true, it would lead to some very interesting results. We should, for example, be able to produce a single galvanic cell of almost unlimited electromotive force by simply mixing together in a porous cup a great number of strong reducing agents, and outside of the porous cup a great many oxidising agents. The electromotive force of the cell would be the sum of the electromotive forces of all the reagents in the mixture. A Bunsen and a bichromate cell, mixed together, would give an electromotive force of nearly 4 volts, and, by adding a Grove cell to the mixture we could get nearly 6 volts. The only difficulty with this theory is that it is not supported by any facts.

As to Mr. Barnett's difficulty in understanding how PbO_2 can be formed by the electrolysis of $PbSO_4$, I think it is only necessary to remind him that $PbSO_4$ is itself an electrolyte, and the products formed are the same as though no water were present, viz.:

$$\overset{+}{PbSO_4} + \overset{-}{PbSO_4} = PbO_2 + Pb + 2SO_3$$

As the SO_3 cannot exist in the free state in presence of water, we have simultaneously formed $SO_3 + H_2O = H_2SO_4$; or, combining in one equation, we have

$$\overset{+}{PbSO_4} + 2H_2O + \overset{-}{PbSO_4} = PbO_2 + Pb + 2H_2SO_4$$

By writing the symbol of lead sulphate $PbO.SO_3$, instead of $PbSO_4$ and Aq for an indefinite quantity of water, the reaction may possibly be a little more apparent:

$$2PbO.SO_3 + Aq = PbO_2 + Pb + 2SO_3 + Aq$$

The only reaction in which the water is concerned is that of combining with the SO_3 liberated as a by-product.

Pure, chemically precipitated $PbSO_4$ is easily and rapidly changed to PbO_2 and Pb by the electric current, references to the contrary notwithstanding. This may be shown by placing a paste of pure $PbSO_4$ and pure water between lead

or platinum electrodes, and passing a current through the mixture. The paste is rapidly converted into PbO_2 and Pb. In this case, at least, there can be no decomposition of the H_2O at the beginning, since pure water is not an electrolyte and no H_2SO_4 is present.

The fact that, in charging, oxygen is given off before any hydrogen appears, is easily explained. The statement that oxygen cannot be liberated without the simultaneous liberation of hydrogen is contrary to all experience. The nature of the ions liberated at the positive and negative electrodes depends upon the electrolytes in contact with each and the working conditions. It is easy, for instance, to liberate, simultaneously, oxygen and either zinc, copper, lead, gold, silver, tin, mercury, or even aluminum, sodium, potassium and barium without any hydrogen.

In the accumulator it is only necessary to suppose that some H_2O_2 is formed along with the PbO_2, and the liberation of oxygen follows necessarily, as these two bodies cannot exist in contact without the immediate reduction of PbO_2 and evolution of oxygen.

It does not seem to me to be necessary to invent improbable theories of chemical reaction in order to explain the formation and decomposition of lead persulphate, when there is no evidence whatever that any lead persulphate is formed in an accumulator, none of it having ever been found.

My remarks in regard to soluble and insoluble active material for an accumulator had reference more to what is desirable than to what has been commercially accomplished. The fact that we have not yet found a commercial accumulator of light weight, or one with a perfectly dry electrolyte, is no indication that it is not desirable. If we are to be content with pinning our faith to what has already been accomplished, and bounding the possibilities of the future by the cobwebs and traditions of the past, then truly we should accept the lead accumulator of to-day as the *summum bonum* and *ne plus ultra.*

MR. BARNETT.—In concluding this discussion, let me say that I quite agree with Mr. Reed that "it is of no interest to discuss these questions on a basis of arbitrary supposition

without any regard to the fact." As some importance attaches to the heat of formation of $PbSO_4$, let us direct our attention to that. I regret that I have not a copy at hand of Thomsen's "Chemical Memoirs," and that I cannot cite the reference requested; but on page 40 of Gore's treatise on the "Electrolytic Separation of Metals," the heat of chemical union of $PbSO_4$, in c. g. calories, is given as 145,130. Referring to this value, Mr. Gore states, at the beginning of the table, that the figures are taken from the Memoirs referred to.

Mr. Reed's contention that this value is too high is not supported by any facts adduced by him. It may be of interest to cite here the chemical formula of the discharge of the lead accumulator, with the corresponding heat of formation of the substances produced. Mr. Reed will then see that there is no ground for doubting the accuracy of the figure for the chemical heat of formation of $PbSO_4$ given by me. We may write the electrolytic equation of the action of the lead accumulator as follows:

$$(2.PbSO_4) + (2H_2O) - 2(H_2SO_4.19H_4O) + [(\text{Electrolyte} + 2(19H_2O + H_2O)] - PbO_2 = 90920 \text{ c. g. calories}$$
$$290260 + 136720 - 277280 \text{ app.} + 3520 - 62300$$

This, according to the method followed by Sir W. Thompson for calculating E.M.F. from thermo-chemical data, corresponds to the development of a pressure of *2 volts*, which is the normal pressure of the lead accumulator. It is thus seen that the heat of formation of $PbSO_4$, as given by me, is not at all at variance with the facts observed in the performance of secondary lead batteries.

I may add that I have not advanced any theory connecting the E.M.F. of the charging current "in series" with chemical affinity. All I have done is to posit sufficient E.M.F. to decompose the electrolyte and effect the ordinary combinations taking place during the charging of the cell. With such an E.M.F. in operation, which, by the way, is sufficient to decompose $PbSO^4$, hydrogen is generated at the negative plate simultaneously with the development of the electrical tension on $PbSO_4$, which tends to break up that compound; and when that compound is broken up, I maintain that the (SO_4) *is not transported to the positive plate, but unites, then and there, with the hydrogen liberated to form hydro-*

gen sulphate. Mr. Reed seems to be wrapped up in the contemplation of those compounds only which yield heat during the combination of their constituents. It might be well, therefore, to remind him that there are "endothermic" compounds (or those that *absorb* heat when their constituents unite) as well as "exothermic" compounds, which *give out* heat when their constituents unite. It does not, therefore, make any difference whether the heat of formation of H_2SO_4 is less or greater than that of $PbSO_4$; if the E.M.F. of the charging current is capable of decomposing $PbSO_4$, then the hydrogen generated at the negative plate will unite with the (SO_4) as long as any $PbSO_4$ remains. This is not opposed to any law enunciated by Faraday, and is in the strictest accordance with the laws of the conservation of energy and the correlation of forces.

Respecting Mr. Reed's unwillingness to accept the view that the E.M.F. of the cell *can* determine a chemical reaction which involves the *absorption* of heat, I can only say that he can point to no authority that will coincide with him. In 1878, Berthelot discovered persulphuric acid, and showed that it was the primary product at the positive electrode when dilute H_2SO_4 was electrolysed. According to Mr. Reed, such a compound could not be formed during electrolysis of H_2SO_4, because it *absorbs heat.* Mr. Reed knows that, in charging an accumulator, there is consumed nearly 20 per cent. of energy in excess of what is needed to overcome electrical resistance. Does it not occur to him that part of this is used in effecting endothermic combinations?

If the E.M.F. needed to charge lead accumulators were capable of decomposing $PbSO_4$ *without decomposing the electrolyte*, such a reaction as Mr. Reed represents,* *i. e.*,

$$\overset{+}{PbSO_4} + 2H_2O + \overset{-}{PbSO_4} = PbO_2 + Pb + 2H_2SO_4$$

would take place. But, as a matter of fact, the charging current is always capable of decomposing the electrolyte. I think, therefore, that I am not at variance with scientific opinion when I state that, when hydrogen is formed at the negative plate, it unites with the SO_4, which is simultaneously liberated there.

* See page 316.

If we reject this view, we must consider that when the electro-negative (SO_4) of the $PbSO_4$ is attracted to the positive pole, the electro-positive (Pb) is attracted to the negative pole. Under continual charging, the negative plate ought to have deposited on it an amount of lead which is only limited by the existence of the positive plate. This view is absurd, yet Mr. Reed is logically led to it by insisting on the pure and independent electrolysis of $PbSO_4$ as being concerned with the charging reactions of the lead accumulator.

Franklin Institute

[*Proceedings of the stated meeting, held Wednesday, March 18, 1896.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 18, 1896.

Vice-President H. R. HEYL in the chair.

Present, 164 members and visitors.

Additions to membership since last report, 11.

The Actuary transmitted the report of the judges appointed by the Board of Managers to examine a memoir submitted in competition for the "Boyden Premium," by an author writing under the pseudonym "Massis." The decision of the judges was unfavorable to the competitor. The report was received and adopted. [Referred for publication.]

Communications were presented from the following:

Mr. Stogdell Stokes exhibited apparatus for making the Röntgen shadowgraphs, and showed some excellent pictures made by Mr. Leeds and himself.

Mr. F. W. Geisberg, on behalf of Mr. Emile Berliner, exhibited the grammophone in its present commercial form.

Mr. W. N. Jennings showed some interesting photographs of "ribbon lightning," and gave an explanation of this appearance. [Referred for publication.]

The meeting then proceeded to the discussion of the "Filtration of Water Supplies for Cities."

Remarks were made by Dr. Albert R. Leeds, Mr. Edwin F. Smith, Dr. Benjamin Lee, Mr. L. Y. Schermerhorn, Mr. Thos. Shaw, Mr. J. Emory Byram, Mr. J. C. Trautwine, Jr., Dr. Goldschmidt and others.

At the close of the discussion, the following resolution was adopted:

Resolved, That it is the sense of this meeting that the Councils of the City of Philadelphia should make an appropriation sufficient to satisfy the requirements of the Director of Public Works for the erection of an experimental filtering plant.

Adjourned.

WM. H. WAHL, *Secretary*.